

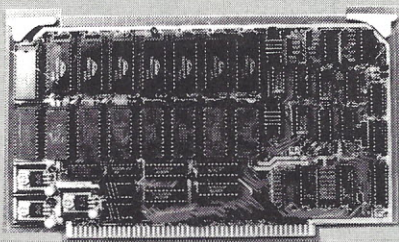
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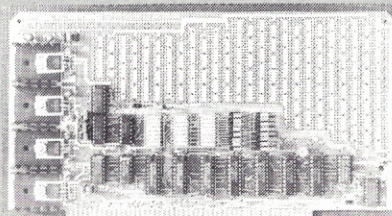


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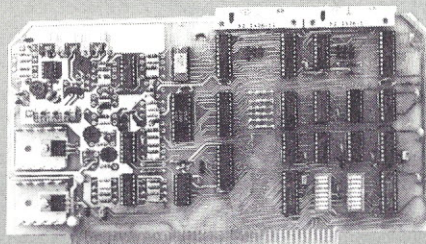
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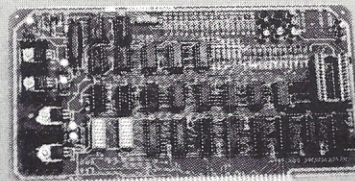
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PROTOTYPING



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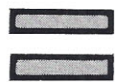
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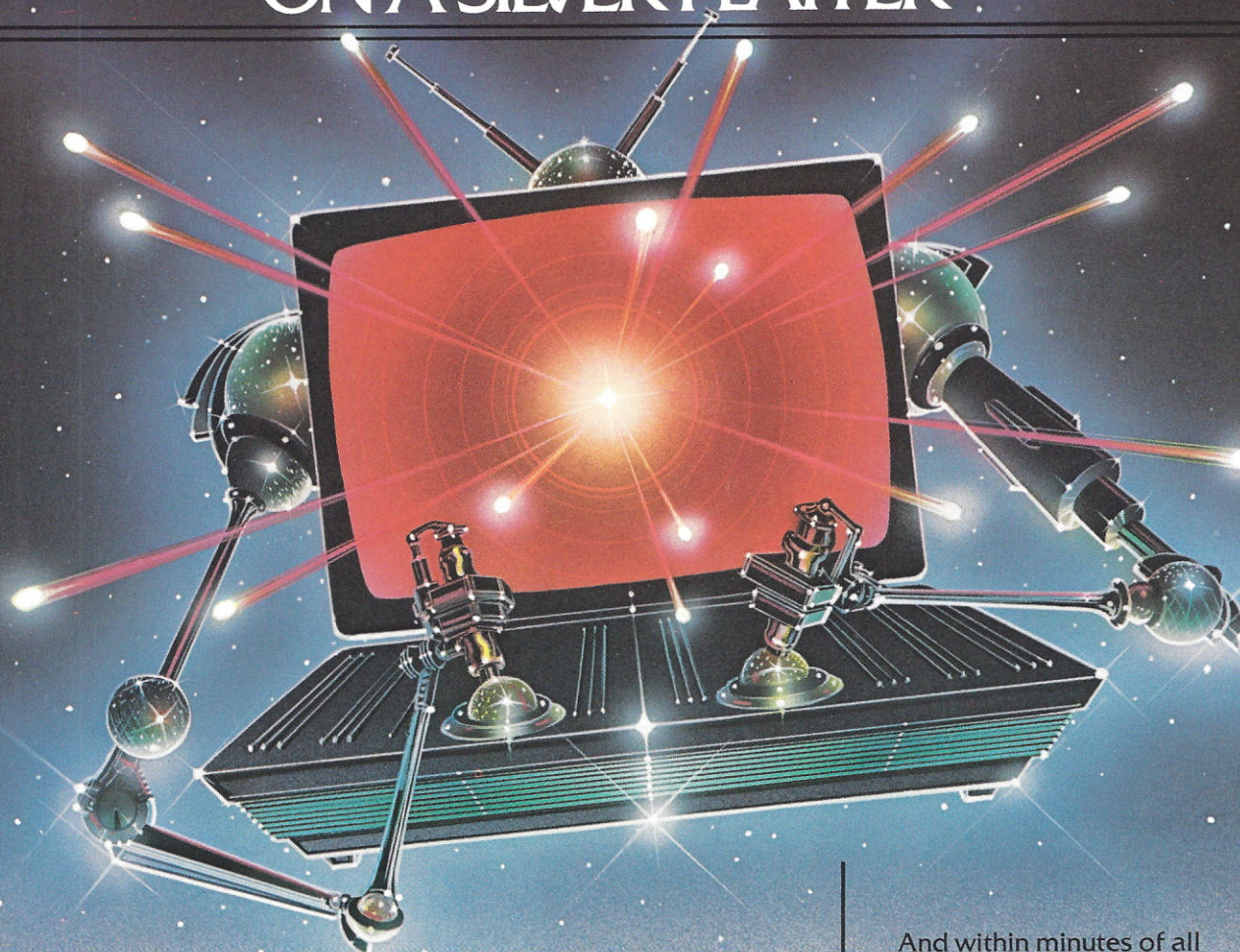
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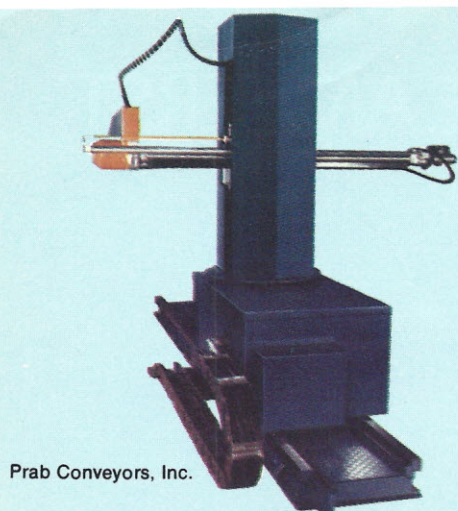
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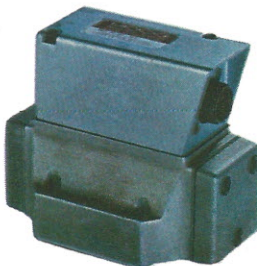
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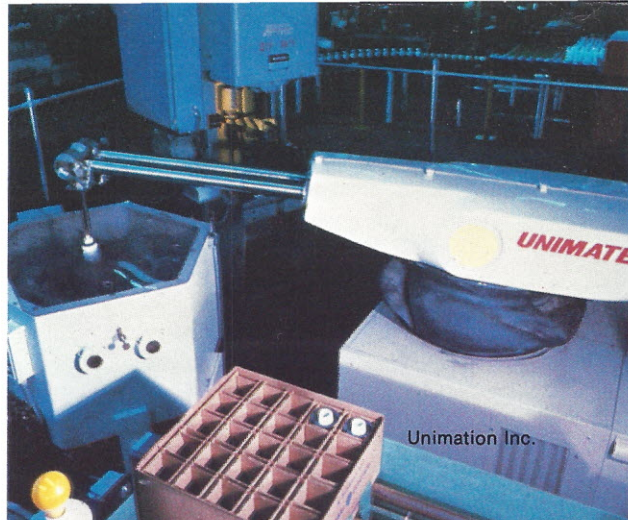
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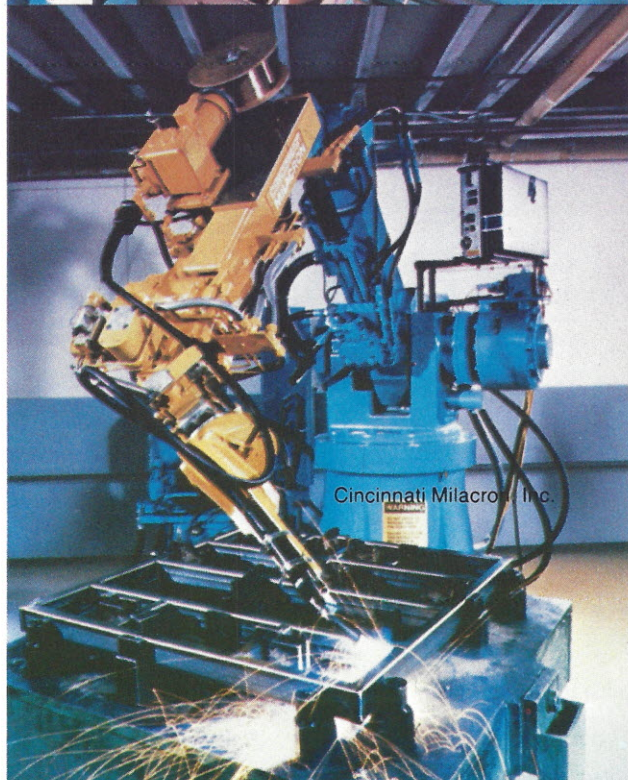
77 Series Servovalve



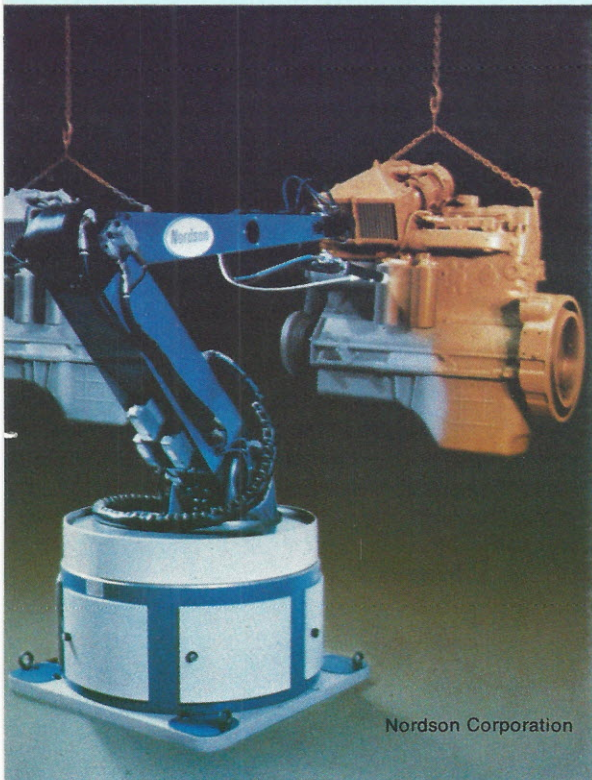
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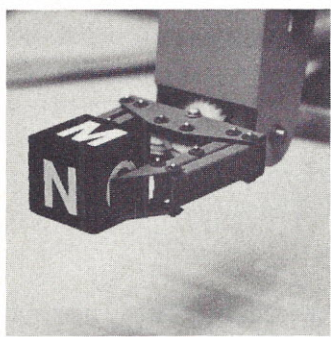
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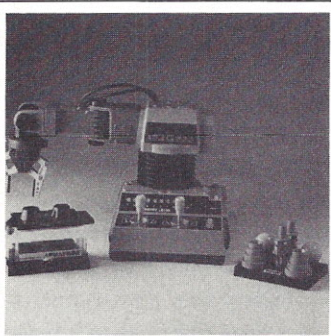
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About The Cover: Our cover this issue is a color picture of the Tomy Toys *Armatron* product, supplied courtesy of Tomy Toys. As noted in Mark Robillard's article on the subject, this provides the world's least expensive (although somewhat light duty) manipulator arm.

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Editorial

Visions of the Future

BY CARL HELMERS

How can a computer see? If we are to create interactive, real-time intelligent machines, many challenging problems have to be solved in areas of computer vision engineering. The applications of vision are many — and the trade-offs of various criteria are not always obvious. Let's look at vision from a general point of view. The object of this exercise is to pose questions rather than answer them. The subject of vision can hardly be exhausted in one short essay.

Why Use Vision? We build robotic systems, in one sense, as an attempt to simulate living organisms. Vision is one of the most highly developed and useful sensory mechanisms of the biological world. We use it all the time, take it for granted, and only realize the magnitude of its loss through accounts of our fellow beings who are blind. The pure goal of simulating the biological powers of sight is one of the driving forces behind vision research. A system that could "see" in some sense would be more powerful than one which could not. And if seeing were impossible, the system might not be possible at all.

Such philosophical arguments provide a background to the challenge of vision systems design. But what about the practical reasons of engineering? The practicality of vision in many situations comes from the reliability and low power-density of the photons used to capture an image. In most situations, the use of a vision system does not change or alter the object being investigated. This is true of any system which uses electromagnetic radiation to extract geometric image information at distance scalings which are large with respect to the wavelength. It is also true of other noncontact, non-imaging senses such as sonar.

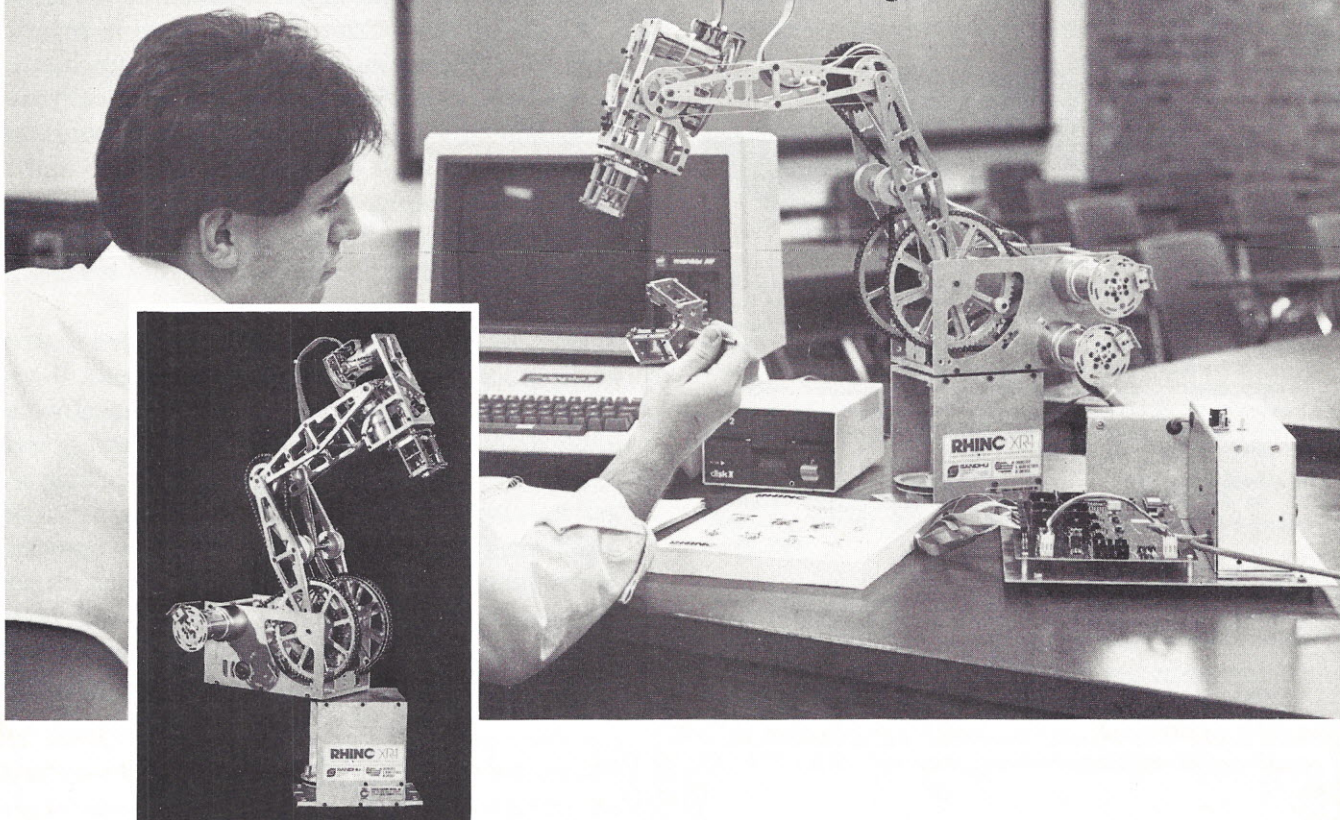
To be sure, there are exceptions. We would not use a vision system operating at light wavelengths shorter than the longest visible red wavelengths in the usual photographic darkroom. We would not use sonar in a situation in which sound of similar frequencies was being measured as well. Vision at optical wavelengths would not be appropriate in oily, dusty, or smoky environments.

A vision system is an imaging system. It reduces a "scene" into a two-dimensional map of geometric information, in which intensity at each picture element ("pixel") bears some relation to the scene being measured. The formation of the image on a plane sensor uses optical techniques with no mechanical coupling to the object being

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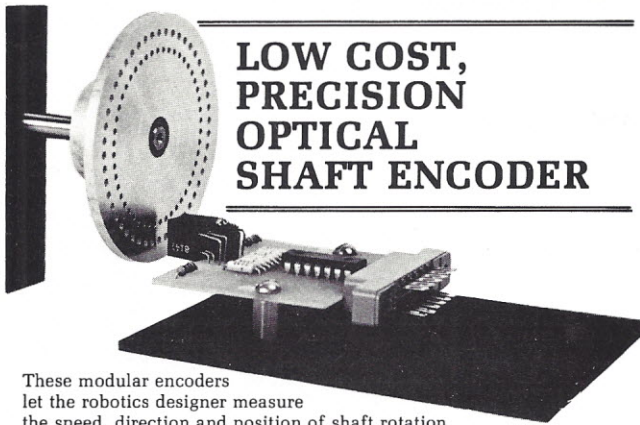
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Editorial

sensed. The image often can be used to inspect or measure in ways that no mechanical system would be capable of. The information obtained is geometrical.

Where do these characteristics excel in practical use? In systems in which delicate mechanical assemblies must be sensed; where mechanical measurements are not amenable to automation; where objects must be found, measured, and inspected. Ultimately, the Holy Grail of the mobile, autonomous servant-robot requires generalized vision capability in direct simulation of living systems.

Where Do We Stand at Present? The video sensor is an accomplished fact of electronics practice. We can get visual field information as an electronically scannable image on a solid state sensor at varying levels of price, resolution, and accuracy. We can then convert the camera information into a pixel map in a computer memory. This pixel map typically associates some binary gray level of "intensity" with each position in a plane array of possible pixels. Commercially marketed black box subsystems can extract information about the presence of objects, their visual field centroids, areas, hole counts, and axes.

Are the systems practical? Practical depends on purpose. I'll give an example from recent personal experience to show trade-offs in a real situation. My associates and I have been evaluating video black boxes in a current design project. The task to be performed is the mechanical adjustment of delicate precision metal parts, using visual feedback to control the results.

The particular process for which we are providing the software engineering is of no great concern for this discussion. It does have a tight time constraint: the adjustments must be completed in 2000 milliseconds. This is a rigid specification determined by the overall throughput rate of a multi-stage manufacturing machine. The machine's concept requires us to allow a cycle of "look," "calculate," "adjust" to operate several times. The outcome will be either of two results. One result is a part which is within quality control specifications. The other result is a part that is tagged in memory for later assignment to the reject bin. As a result, our 2000 milliseconds are fairly busy. What this really means is that the analysis of the information we require has to be accomplished in 100 milliseconds or fewer if our use of vision is to be practical.

Our other technical constraints in this application are pixel resolution and accuracy. The pixel resolu-

Editorial

tion has to be at least 128-by-128, with gray levels in binary form. The accuracy of the sensor's map of the focal plane also has to be adequate.

Since this project involves a manufacturing automation machine of some complexity, the economics allowed any of several systems in the \$20,000-and-under class. The prime constraints are speed and resolution; a minor secondary constraint is compatibility with a particular, widely available microcomputer hardware bus structure.

Over 100-by-100 Pixels in under 100 Milliseconds? Good Luck! That's the reaction we got from a number of vision systems houses. Our problem, fortunately, does not require an order of magnitude better than the best contemporary technology. The difference is in the nature of our problem's trade-off of generality versus a specific case. The nature of our actual requirement should serve as a guide to those who want to engineer usable vision systems.

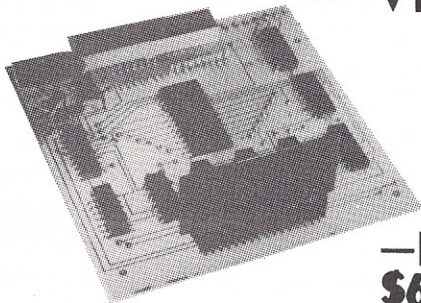
It turns out that our analysis is far from general: our application requires only a selection of two col-

umns in the rectangular array of possible pixels. With this constraint, processing times under 100 milliseconds are not impossible. Our minimum time is that required to capture a full frame at standard composite video rates. This minimum overhead is a worst case of 33 milliseconds (1/30 of a second). The exact interval depends upon image capture command phasing relative to the free-running clock of an unsynchronized camera. This leaves us roughly 66 milliseconds to analyze the image following image capture.

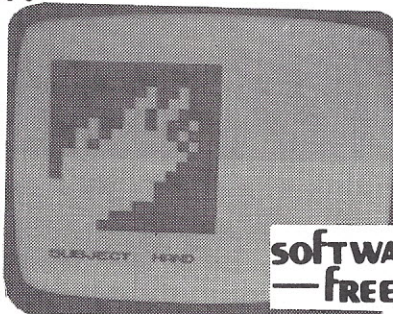
By requiring 100 milliseconds total, we rule out certain forms of image-capture hardware. The image digitization must be done in real time, using direct memory access (DMA) techniques at video rates. One system we looked at, for example, proved totally inadequate. It used a microprocessor to control the capture of data and programmed loading of the pixel map in memory. This is a process which requires repetitive sampling carried out over many video frames. As a result, its minimum expected time to capture a relatively low-resolution, 128-by-128 pixel map was quoted at about 600-800 milliseconds. This was

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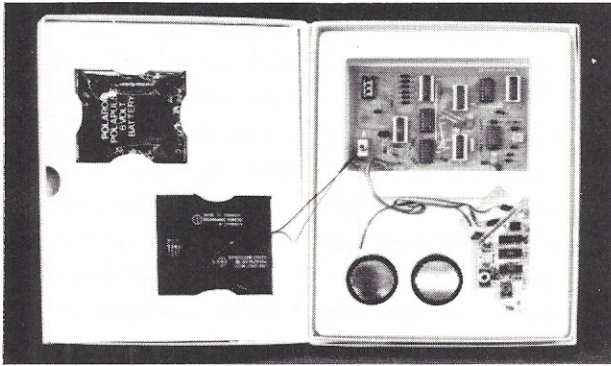
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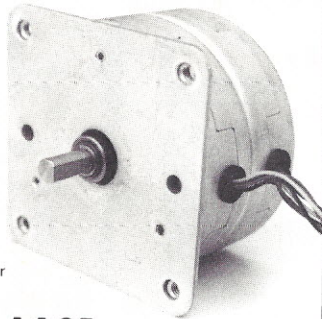
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Editorial

before any image analysis was performed.

The vision subsystem we finally specified was chosen on the basis of its ability to capture an image in a single video frame time. Its actual resolution was some 240-by-320 pixels, as set by the characteristics of the solid state camera being employed. So, within 33 milliseconds of our "snap a picture" command, we have a memory array available with enough eight-bit pixels to say we have a "picture." The nature of our problem, then, is to come up with an image analysis for our purposes in as little time as possible above the fundamental 33 milliseconds worst-case image-capture time.

In Vision Software, Generality Takes Precious Real Time. One thing we can do without, in this particular time-limited problem, is generalized vision software. We have no need for a general analysis of the pixel array to identify object characteristics such as location, centroid, symmetry axes, perimeter length, hole count, and area. As in any problem, constraining the possible states of data reduces the complexity of the analysis. In our case, the geometry of the problem considerably reduces complexity.

We are dealing with a manufacturing system with tight mechanical control over the scene to be inspected. The same precision part is always tightly clamped in to the same visual field. The vision system is used to give feedback from a mechanical adjustment of this part. The only information needed is measured along two parallel lines in the visual field. Our analysis is really a pair of much smaller one-dimensional problems, not a generalized two-dimensional scene analysis.

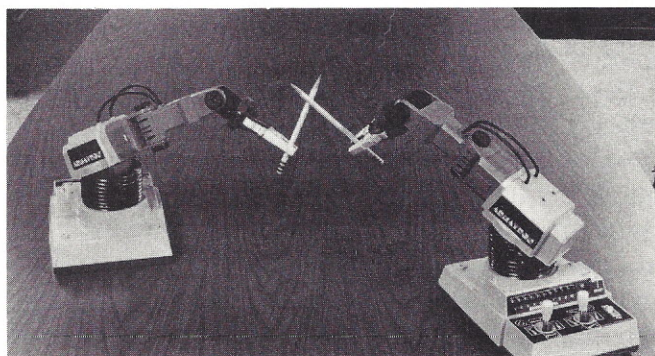
While we want to use a standard, readily available vision system, all we really need is two scan lines from the pixel array. Our recognition is in one dimension, along these scan lines. Since we already know what our object is, any puzzling results are grounds for rejection. If time allows it, characterization of the usual state of the rest of the visual field may be tried on an experimental basis. Since we already know the object is properly oriented, all we have to do is define an image threshold level and then measure the width of regions above and below that threshold. The mechanical effects of an adjustment are seen as the width (in pixels) of measured visual regions above and below the current threshold.

If the system were manufactured on a mass production basis, the general-purpose vision system is un-

Editorial

necessary. Since all we need is two lines in the visual field, one of many linear array optical sensors could be substituted for the general-purpose camera and full video imaging system. In small numbers, however, a pre-engineered black box that is more general than needed works fine. It even allows the possibility of incorporating more general analysis later.

The company selling the vision system tends to assume that general-purpose object acquisition and characterization is the definition of the vision system requirement. The whole point of the essay is thus: much can be done with vision, even if general-purpose vision software is not used. And much more can be accomplished on tighter time schedules when generality is purposely sacrificed for speed. Similarly, resolution and accuracy don't always have to be of the highest priority if a simpler, less expensive sensor will do. Such trade-offs between generality and customer engineering are the most crucial judgements to be made by practitioners of robotics. Reader feedback and opinions are solicited on the subject of generality versus specific solutions. □



1983 TOY ARM CONTEST

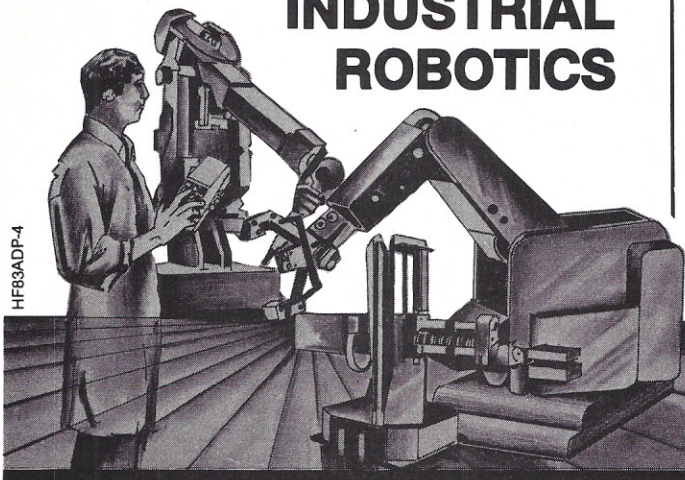
With this issue's feature by Mark Robillard on the adaptation of an inexpensive and widely available toy to robotics contexts, we'd like to announce a new contest: the 1983 Toy Arm Contest. Ground rules are simple:

We are looking for the most imaginative adaptation of the Tomy Toys Armatron or any equivalent robotic toy in the under \$100 price class. Such adaptations should be a significant enhancement to the use and con-

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trol of the system. Mark Robillard's article can be taken as a starting point — or prospective contestants might take their miniature Phillips screwdrivers in hand and analyze their operation from a completely different point of view.

Key to all entries is that the arm *must be interfaced reliably to computer control and then applied to some purpose*. Purposes can range from playing chess to aiding the handicapped. Methods of interface can range from either of Mark's nonintrusive methods, to complete reworking of the clutch control assemblies under the joysticks. Prime movers for control can be opposing solenoids, pneumatics, model aircraft servos, stepper motors, or what have you. The purpose is to illustrate methods of interfacing computers to mechanical systems with this low-precision toy arm as an object of discussion.

Adaptations with a serious educational purpose will be greatly prized. One very high-priority class of adaptation will be the kind which illustrates use of negative feedback from sensors of any kind (vision, sonic, mechanical, capacitive, and so on) to overcome the considerable mechanical backlash inherent in such inexpensive mechanics. We all know that as humans we can overcome the Armatron's loose mechanical system

— therefore it becomes a challenging demonstration of engineering skills to design a system which will do the same. Stretching the point a bit, we'll consider *any* arm design which uses all or part of the original Armatron or equivalent.

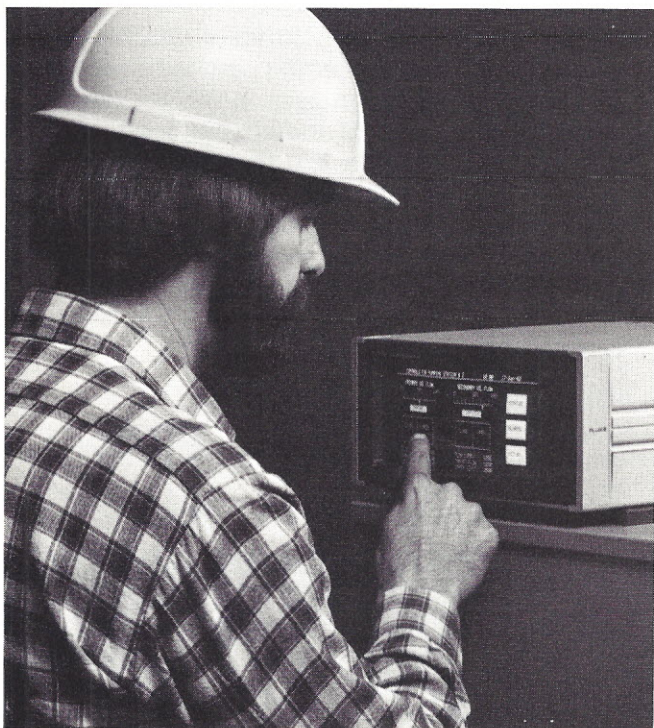
Entries for the 1983 Toy Arm Contest must be postmarked by June 30, 1983. All entries must be accompanied by a descriptive text, photographs, and drawings, using publishable technical writing style as described in the *Robotics Age* Authors' Guide. Prizes? A bound set of *Robotics Age* back issues will be awarded to the winner(s) as evaluated by our editors.

AUTHOR GUIDE NOW AVAILABLE

We have now completed the first *Robotics Age* author guide. This 26-page document contains detailed information about technical writing in general and writing for *Robotics Age* in particular. Potential authors can obtain a copy by sending a self-addressed, stamped envelope with enough postage for four ounces, first-class mail.

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CIRCLE 11

Media Sensors

Electronic News ***19 July, 1982, page 11.***

TeleOperator Systems Corporation will introduce a general-purpose industrial robot aimed at domestic machine tool manufacturers. A lifting capacity of 16 pounds and repeatability to within 0.004 inch will make the robot suitable for welding, machine loading and unloading, and intricate assembly operations. TeleOperator expects their robot line to meet 85 percent of expected robot tasks over the next five years.

The Christian Science Monitor ***17 August, 1982.***

Robots suffer from joblessness, too. "Lured by forecasts of a . . . \$1 billion [market] by 1990, scores of firms jumped into the robot business." The reality is that, due to the current state of the

economy, many companies are cutting back on machine orders. This has served to intensify the already fierce, competitive battle.

Efforts to bolster sagging automobile and farm equipment sales promise to speed the development of new robot uses. The long-term outlook for the robot industry appears promising. Laura Conigliario, vice-president of Bache Halsey Stuart Shields, sees "no reason . . . to change my long-term trend."

The article states that the 1982 growth rate is half that of 1981. Estimates of total robot sales range from \$195 million to \$290 million. The introduction of many new companies to the industry has helped to increase sales. Another boost for sales is a switch in emphasis from the automotive industry to industries which, until recently, had not been considered as potential markets. Typical new market applications include food processing, electronics, and light mechanical assembly.

In summation, Philippe Villers, chairman of Automatix, Inc., is quoted saying that, "advanced or intelligent robots have enormous potential and customers don't want to put together the large teams [needed to design and build robot systems] themselves."

IEEE Computer ***August, 1982, page 39.***

Imprecision in Computer Vision describes a heuristic approach to robot vision systems. Researchers realize that definite relationships cannot always be determined from the information entering the vision system. Hard and fast analytic tools are not appropriate in a vision system.

Imprecision arises from many sources: illumination, surface properties, geometrical shape, viewing angles, and occlusion of objects by the vision system's own parts or other objects. There are also problems associated with projecting the real, three-dimensional world onto a two-dimensional image and then attempting to extract three-dimensional information. The complexity of the information leads researchers towards the study and application of "fuzzy set" theory.

In summation, the authors "believe that computer vision systems should exploit approximate reasoning, opportunistic procrastination, and knowledge . . . By combining fuzzy sets with probability (for handling uncertainty) we get a rich and compact methodology for approximate reasoning."

Electronic Engineering Times ***2 August, 1982, page 2.***

Air Force Plans Three-Task Program for Applications of Robotics. The Air Force has issued a final request for proposals related to expanded work in its Man Tech robotics program. The new work, is part of a program seeking to make aerospace robotics more flexible and accurate. One covers extensions to MCL, an off-line Manufacturing-Control Language which allows great flexibility in robot functions. The language is particularly applicable to robot systems which must be reprogrammed often for a variety of tasks. A second task covers adaptive control development to improve robot accuracy. Another task calls for a demonstration of innovative use of robots in aerospace manufacturing.

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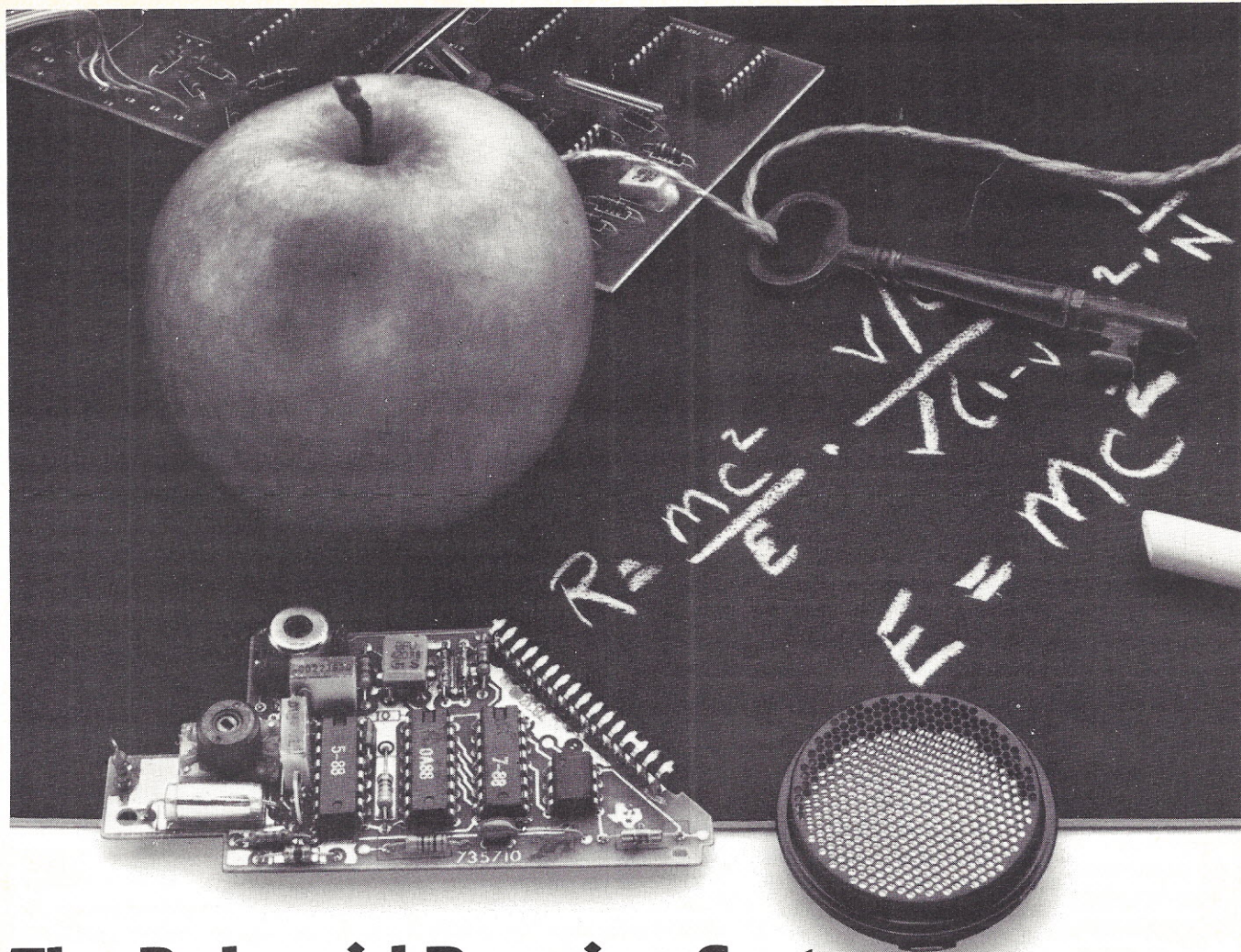
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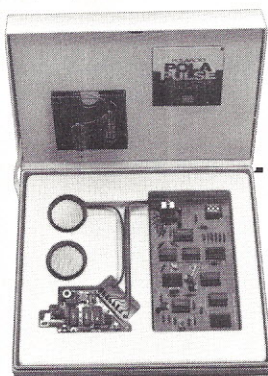
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Calendar

AUTOFACT 4 To Zero-in On Automated Factory

Nearly 100 experts in computer-based technologies will make presentations at the AUTOFACT 4 Conference and Exposition at the Philadelphia Civic Center, November 29-December 2, 1982. The four-day high-technology convention will cover all phases of automated production. AUTOFACT 4 is expected to attract a heavy turnout of manufacturing executives and engineers.

More than 100 companies will demonstrate equipment and systems used in computer-integrated manufacturing (CIM). Exhibits include CAD/CAM equipment such as interactive graphics and software, CIM control systems, automated assembly and fastening systems, computerized storage/retrieval and material handling systems, industrial robots, machinery diagnostic and sensor systems, and computerized test, measuring, and on-line inspection systems.

For more information, contact: CASA/SME, One SME Drive, PO Box 930, Dearborn, Michigan 48128. Phone: (313) 271-1500.

SME Plans Conference and Exhibition

The Society of Manufacturing Engineers announces MACH-TECH International, a five-day world production equipment event to be held in Chicago, December 5-9, 1983. The first MACH-TECH International will be held at Chicago's McCormick Place. MACH-TECH International will emphasize the latest high-technology developments in machine tools, controls, transfer systems, and production engineering equipment from many countries.

For more information, contact: SME Expositions Department, One SME Drive, PO Box 930, Dearborn, Michigan 48128. Phone: (313) 271-0023. TWX 810-221-1232 SME DRBN.

Call for Papers for International Meeting on Advanced Soft- ware in Robotics

Authors are invited to submit proposals for papers to be presented at the International Meeting on Advanced Software in Robotics to be held in Liege, Belgium, May 4-6, 1983. Software contributes to the essential qualities of robots, giving them higher dynamic performance, better perception of the environment, and improved adaptation to their tasks. The conference aims to be a forum for discussion between those involved in advanced software in robotics. Papers are requested on: control language, data acquisition in processing software, artificial intelligence software, software reliability, kinematics and dynamics modeling, adaptive control, high level languages, distributed processing, computing aspects of sensing devices, and interfacing with the environment.

Anyone interested in participating in this meeting should send name, title, organization, address, and proposed topics to: A.I.M., rue Saint-Gilles, 31, B-4000 Liege (Belgium) as soon as possible. Text should be received by the program committee no later than Dec. 1, 1982 and should not be longer than 20 pages, single-spaced. Authors of accepted papers will be notified by Jan. 31, 1983, at which time they will receive instructions for preparing the final copy.

A discussion will follow presentation of the papers by their authors at the meeting. The proceedings will be available as a paperbound book.

Test & Measurement World Expo

The second annual Test & Measurement World Expo will take place May 2-5 at the San Jose Convention Center in San Jose, California. The in-depth technical program is divided into 10 technology tracks. The technical program is designed to allow participants to attend two complete tracks. The 10 tracks are failure analysis, EMI/RFI evaluation, optical inspection, test software, subassembly/system ATE, component test, VLSI test, microelectronics measurement, test instruments, and communications/microwave test.

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Continued on page 34.

ROBOT WRIST ACTUATORS

Mark E. Rosheim

417 Grand Ave., St. Paul, Minnesota 55102

Richard Hohn, head of the Robotics Division at Cincinnati Milacron, says that, "The wrist actuator takes 90% of the creativity of the mechanical design of the industrial robot." This statement reflects the feelings of many corporations who hope to obtain a larger share of the industrial market by producing more mechanically sophisticated robots. The ideal wrist is one which is compact, powerful, dexterous, and precise. Most robots used in welding, material handling, paint spraying, assembly, and working in a cramped space or performing complex maneuvers would benefit from improved wrist design.

This article's goal is to help mechanical designers or engineers design improved wrist actuators which have three or more degrees of freedom. I will examine the human wrist as a model for robot wrist performance, and the different kinds of wrist actuators in current use and in the prototype stage of development. I will also try to anticipate future trends and suggest design criteria for wrist actuators.

The Human Wrist. A sophisticated robot should have a wrist with at least the three degrees of freedom and range of motion of the human wrist. The human wrist (figure 1) is capable of moving the hand approximately 170 degrees in the radial/ulnar deviation mode and approximately 70 degrees in the flexion/extension mode. It can also move in a compound of these modes.

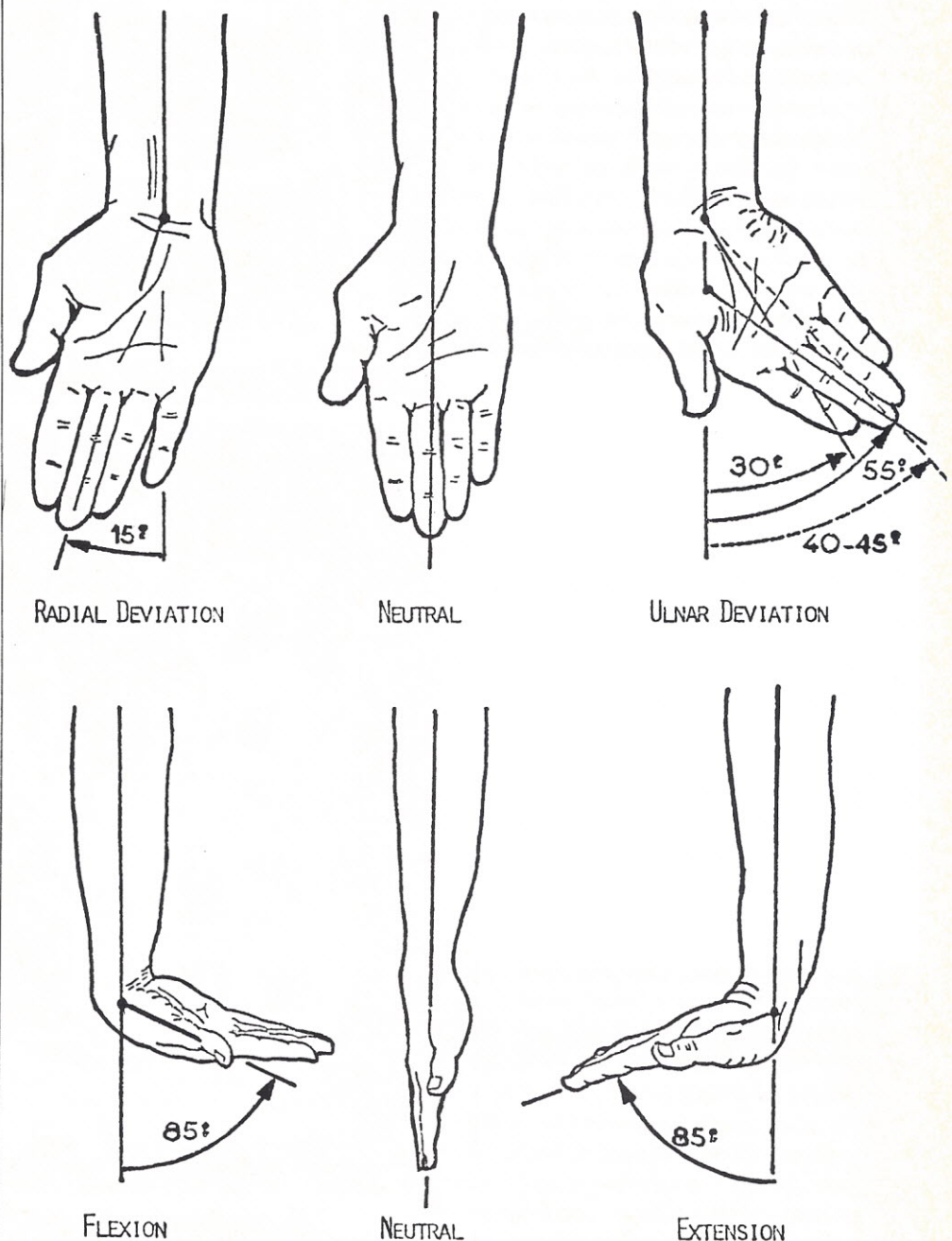


Figure 1. The human wrist radial/ulnar deviation and flexion/extension motion (from Kapandji).

The entire wrist may be rotated approximately 270 degrees by the forearm muscles and the upper-arm muscles.

The wrist is driven by muscles located away from the wrist. Tendons and arm bones communicate the muscle power to drive the compact group of bones that make up the wrist. This design allows for larger, more powerful muscles than can be in the immediate wrist area.

Kinds of Robot Wrists. Robot wrist actuators are typically divided into three categories: direct-drive hydraulic wrists, direct-drive electric wrists, and remotely driven mechanical wrists.

The ideal robot wrist simulates the three functions of the human wrist. In aeronautical engineering terminology they are: pitch, yaw, and roll (figure 2). Current robot wrists have a pitch and yaw range of motion from 180 degrees to 230 degrees. "Tool plate" roll varies from approximately 240 degrees to 360 degrees continuous rotation. A means of supplying the end effector, such as a gripper with pressurized air, for its actuation is also important.

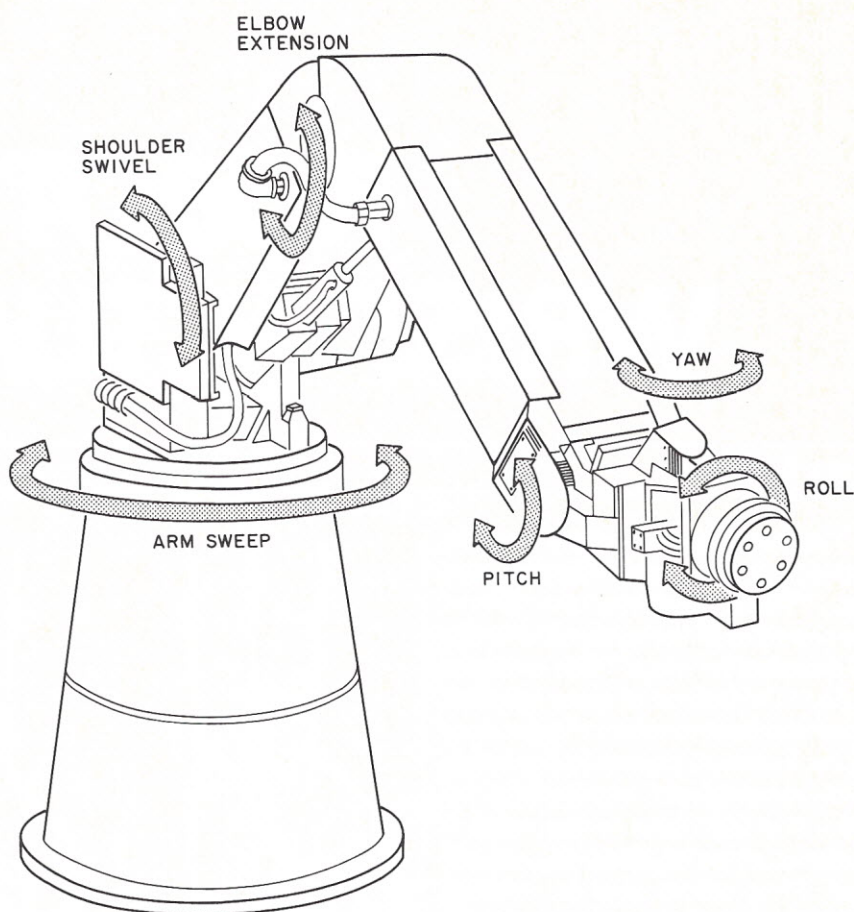


Figure 2. The three degrees of freedom of the robot wrist.

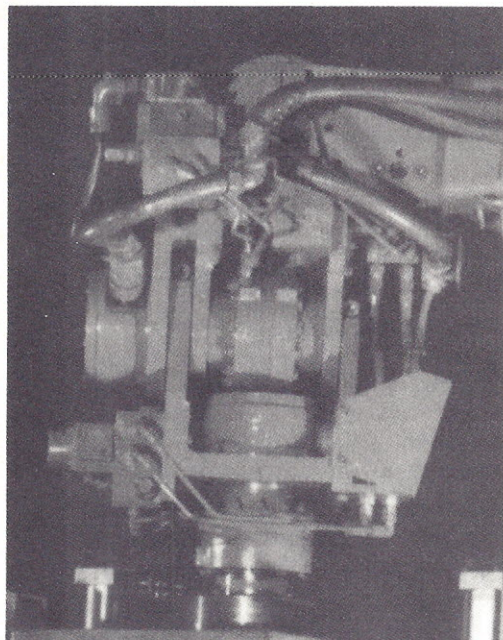


Photo 1. The old Cincinnati Milacron hydraulic wrist. Photo courtesy Cincinnati Milacron.

Direct-drive hydraulic wrists usually consist of three hydraulic rotary vane actuators coupled together (photo 1). The vane actuator is a simple form of hydraulic motor which has a limited drive shaft rotation. These are widely

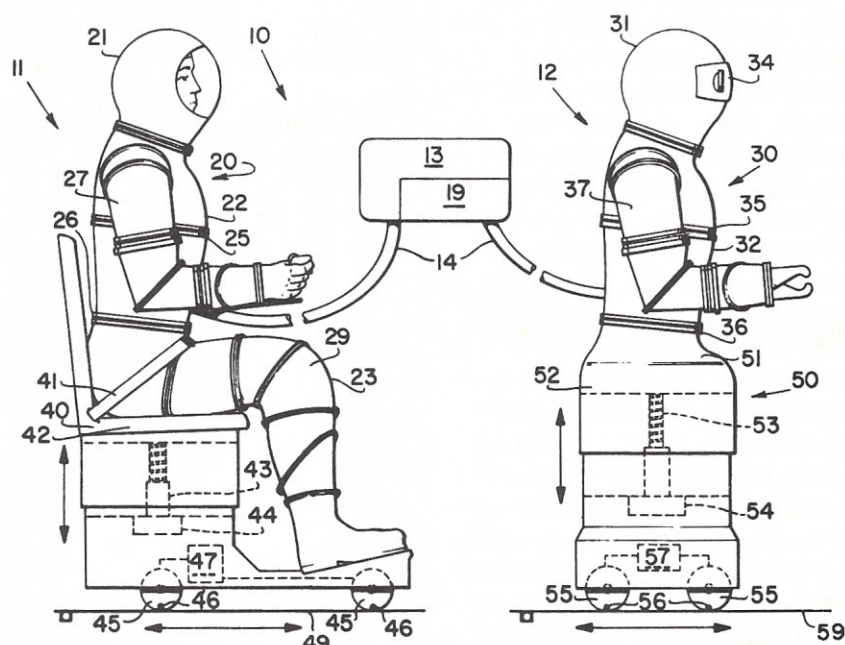


Figure 3. The NASA anthropomorphic master/slave robot which is an outgrowth of the NASA hard space suit.

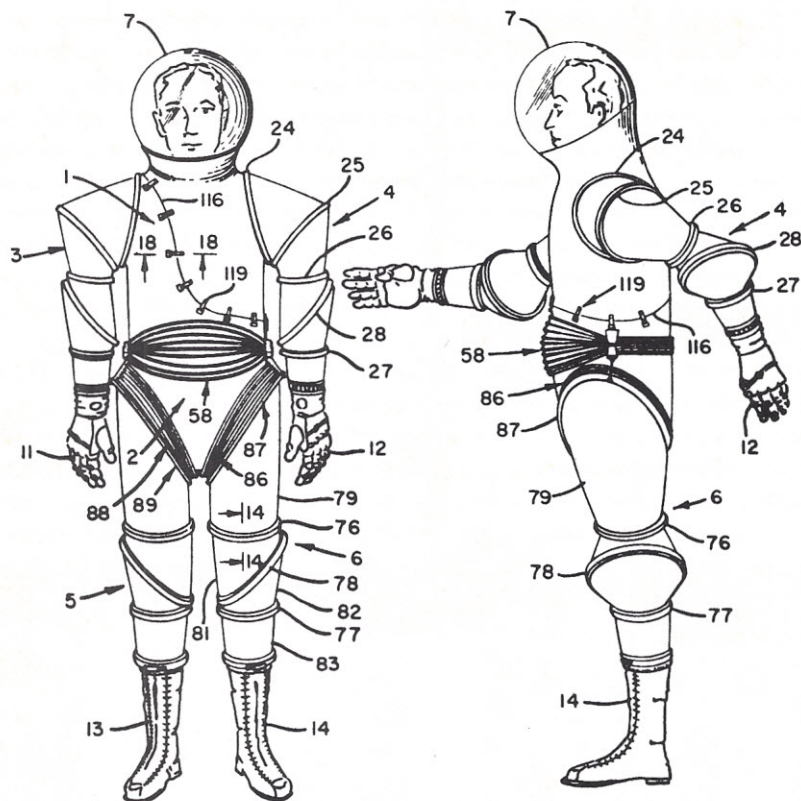


Figure 4. The NASA hard space suit.

used in industry, which requires a powerful, compact, limited rotary motion. (A new kind of hydraulic rotary actuator, "the Helac," which is more compact than conventional rotary actuators, is being offered by Weyer Machine Co.)

The pitch actuator is attached to the forearm of the robot. The yaw actuator is connected to the pitch actuator's drive shaft by a frame. The roll actuator drives the tool plate and is supported by a frame connected to the pitch actuator's drive shaft. (A complete, improved direct-drive hydraulic wrist is offered by Byrd-Johnson. Its improvements include upgraded bearings and mechanical connections.)

A tool plate provides a mounting surface for end effectors. In an effort to make a more compact configuration, some companies position the roll actuator underneath the yaw actuator (photo 2). This shortens the length of the wrist but increases the overall diameter. Flexible hydraulic lines go from the actuators to servo valves mounted on the arm. Position sensors on the actuators provide position feed-

back information for the servo loop. Removing the servo valves from the wrist and putting them down-line on the arm makes the wrist more compact. This causes a loss of precision, however, because of sponginess in the additional flexible lines.

Potential advantages of this type of wrist include the wide availability of hydraulic vane actuators and their proven reliability. Hydraulic vane actuators also come in a variety of sizes. Wrists using such actuators may be back-driven so that the operator can program the wrist's motions of the task to be learned. This may be done on-line, in the actual work station. The ability to be back-driven is a very valuable feature in most applications which require robots of near-human size. Larger robots are too dangerous to program by hand.

One potential disadvantage is that the vane actuators have a very bulky profile because the yaw and pitch motions occur in separate planes. The tool plate is further separated from the first axes of movement by its actuator. The flexible hydraulic lines create

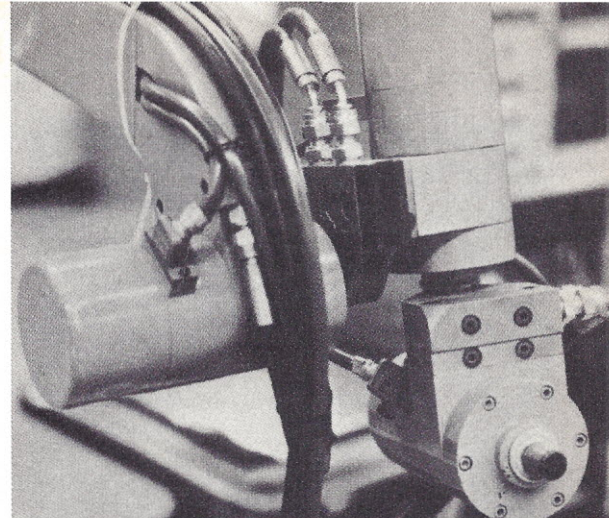


Photo 2. The DeVilbiss standard hydraulic paint spraying wrist. Photo courtesy DeVilbiss.

sponginess in the hydraulic system and subsequent loss of precision. The hydraulic line and position sensing wires add considerably to the bulkiness and may be subject to fatigue and abrasion. The hydraulic lines must be fed through or around the other joints in the robot. The potential leakage of the hydraulic seals and connections is another concern in environments that must be contamination-free. There are friction problems with a conventional actuator's bearings and potential backlash problems with the spline connection between the actuator and brackets which may cause loss of precision.

Direct-drive electric wrists are not yet commercially manufactured. The use of electric motors in the wrist itself, however, may become more popular because of improved high-torque electric motors using stronger, more powerful, rare earth permanent magnets such as samarium cobalt magnets, and because of the growing number of all-electric robots.

NASA has successfully used high-torque electric motors in the wrist of the Space Shuttle robot arm (photo 3). It employs electric motors in a configuration similar to that used in the previously described hydraulic wrist, with the electric motors replacing the hydraulic vane actuators. Position sensors are located on the motor shafts to provide position information as in the hydraulic vane actuators.

An advantage is that using electric motors eliminates some of the bulkiness caused by hydraulic lines in the hydraulic wrist. The Space Shuttle

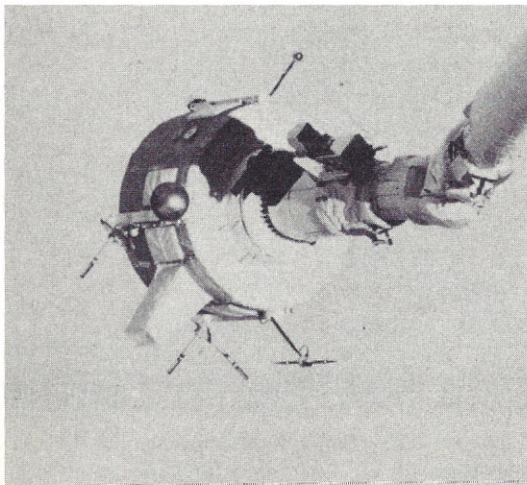


Photo 3. The NASA Space Shuttle electrical robot arm wrist. Photo courtesy NASA.

robot arm wrist uses flexible wires to transmit electrical power from power lines to the yaw and roll actuator. The use of electricity also eliminates potential leaking and costly servo valves.

Although it is more compact than hydraulic wrists, this particular configuration is still bulky. The pitch and yaw actuators are separated; that is, one motor is on top of the other. Placing yet another motor on top of the pitch and yaw motors further increases the bulkiness. As in all electric wrists, they cannot be used in potentially explosive environments, such as for paint spraying.

NASA has developed an anthropomorphic master/slave robot (figure 3), apparently an outgrowth from their hard space suit (figure 4). These concepts are intriguing, but I will discuss just the wrist actuator from the anthropomorphic robot (figure 5).

It resembles an adjustable stove pipe fitting. Two tubular sections are connected together at an oblique angle by a ring bearing. Three internally mounted electric motors drive the wrist. (NASA has also considered using hydraulic motors in place of electric motors in their anthropomorphic robot.) Back-to-back to the drive motors are potentiometers and a tachometer, which provide position feedback information. For pitch motion, the base motor rotates the entire wrist while the pitch motor rotates the second tubular section. The roll motor drives the tool plate to correct for its

rotation caused by the wrist pitch motion.

This design has a great range of motion or working volume. The 360 degree continuous tool plate rotation increases the overall versatility of the wrist and is an advantage in applications requiring limitless rotation. Tools requiring continuous rotation, such as a screwdriver or nutdriver, can be used with this feature.

The NASA anthropomorphic wrist has a solid, sealed housing, which makes it very rugged. Pressurized air for the gripper can be supplied through the wrist internally, eliminating the need for an external tube and making the wrist even more compact.

down. The entire wrist must first rotate 90 degrees, putting the second wrist's axis of rotation in the pitch actuation position (figure 7). This dwell, if long enough, would seem to make the wrist unworkable for paint-spraying applications where a buildup of paint might occur during the dwell time. This would also seem to make it unworkable in applications in which the wrist must be able to move to any position smoothly, without having to slow down. The wrist's power is limited to the size of the motor that can fit into the wrist.

Remotely driven mechanical wrists are the closest mechanical analogy to the human wrist and, in my point of view, the most interesting of the new

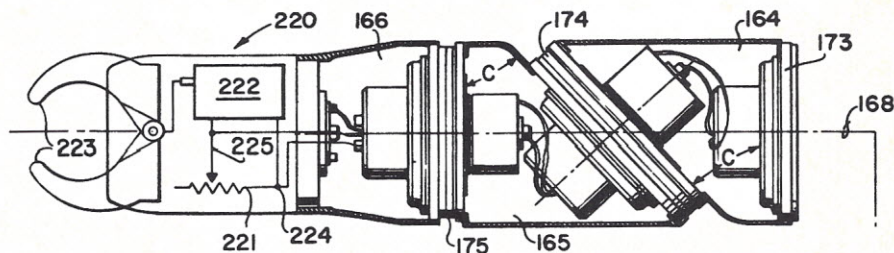


Figure 5. Cutaway view of the wrist from the NASA anthropomorphic master/slave robot.

It is not possible to back-drive the NASA wrist, thus losing the capability for quick, on-line programming. With the inability of the wrist to be back-driven, the wrist has a considerable dwell time. This occurs when the wrist (figure 6) is directed to move up or

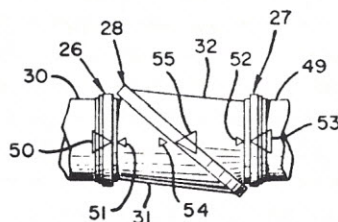


Figure 6. An individual joint from the NASA hard space suit : yaw position mode.

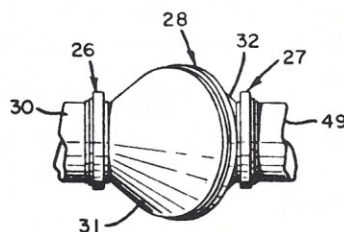


Figure 7. An individual joint from the NASA hard space suit : pitch position mode.

wrists. As in the human wrist, the actual power source for the actuation of the wrist is removed from the wrist area. Rotating drive shafts, linkages, and cables are used to provide a means to communicate the actuation power source to the wrist. The power source may be located in the forearm, arm, trunk, or base. Various power sources can be employed, such as electric motors, hydraulic motors, or hydraulic cylinders, with less concern for size and weight. This has been accomplished recently in two ingenious ways: the Flexiarm used by DeVilbiss and Graco and the 3-Roll Wrist developed by Cincinnati Milacron.

The Flexiarm (figure 8 and photo 4) consists of four redundant gimbal rings connected together. Six hemispherical, concentrically grooved shells act as the two axis gears to communicate two-axis motion from one gimbal to the other. Two linkages connect at the first gimbal of the wrist. These move back and forth to drive the wrist up to 180 degrees in pitch/yaw motion. By rotating the central supporting shaft, the en-

tire wrist may be rotated to provide tool plate roll of up to 370 degrees. Rotating the whole wrist to provide tool plate roll is possible without changing its pitch and yaw position.

Double-acting hydraulic cylinders drive the wrist linkages. In the DeVilbiss robot, the hydraulic cylinders are mounted in the arm. In the Graco robot, the hydraulic cylinders are located in the base of the robot, and the power is transmitted from the hydraulic cylinders, through additional cables, to the wrist.

The Flexiarm is compact, making it useful in operating in cramped quarters, such as painting the inside of a filing cabinet. It can be driven by low-cost, double-acting hydraulic cylinders and can be back-driven by the operator on the work site to program the wrist motions.

The Flexiarm is complicated, however, and has a large number of parts and mechanical connections, making it less reliable and precise than other mechanical wrists.

The hemispherical two-axis gears are expensive and difficult to manufacture. The arm requires a flexible covering to protect the inner mechanisms. This covering is subject to fatigue and wear. The tool plate is a considerable distance from the first gimbal ring, causing a mechanical disadvantage and loss of mechanical efficiency.

The 3-Roll Wrist (figures 9 and 10) essentially uses the basic principle originally developed by NASA, as mentioned earlier. The difference is that the 3-Roll Wrist substitutes a gear system in the wrist for NASA's electric motors, so that it can be driven remotely. Three concentric drive shafts (figure 11) power the wrist by either electric or hydraulic motors at the top of the forearm. Having the motors removed from the wrist itself allows larger, more powerful motors to be put in the wrist; thus, a more powerful wrist is achieved.

The solid center shaft (figure 10, reference 19) drives the tool plate through the four smaller bevel gears (references 21 through 25). The upper

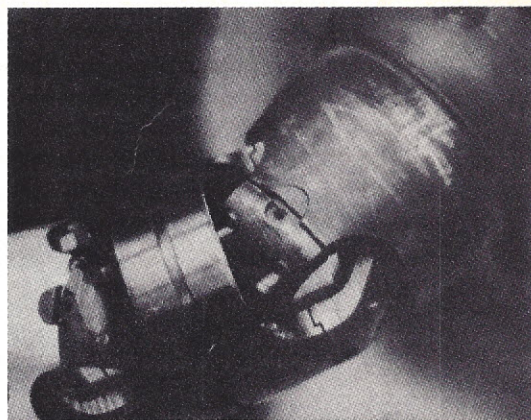


Photo 4. The Flexiarm robot wrist in a partially rotated position. Photo courtesy NASA.

hemispherical section of the wrist is driven by the second tubular shaft; this drives the bevel gear (reference 17) that meshes with the large ring bevel gear (reference 18), which is attached to the upper hemisphere. The ratio between these two gears gives an important speed reduction.

The 3-Roll Wrist has a great range of motion — 230 degrees pitch and yaw.

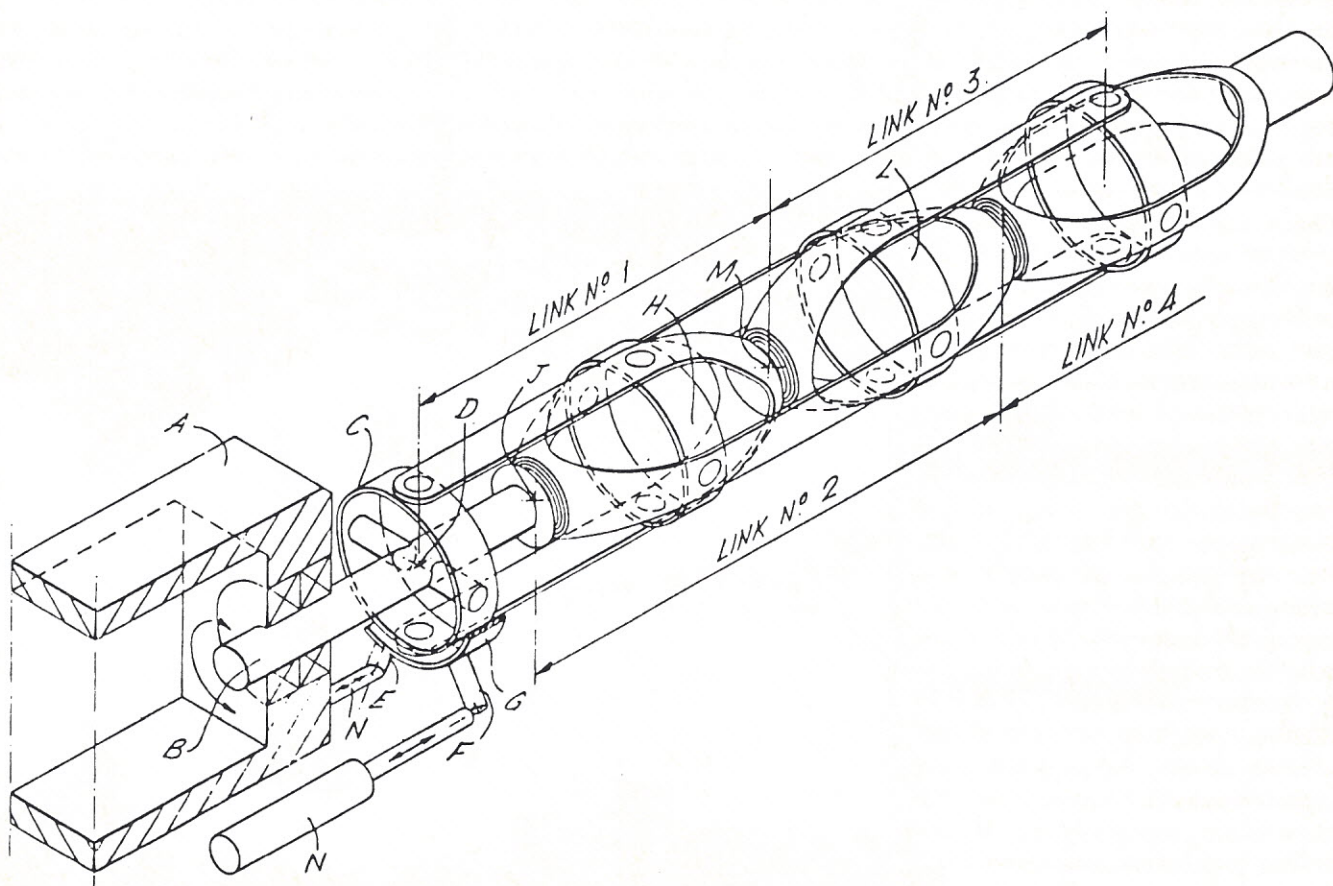


Figure 8. Flexiarm robot wrist marketed by DeVilbiss and Graco.

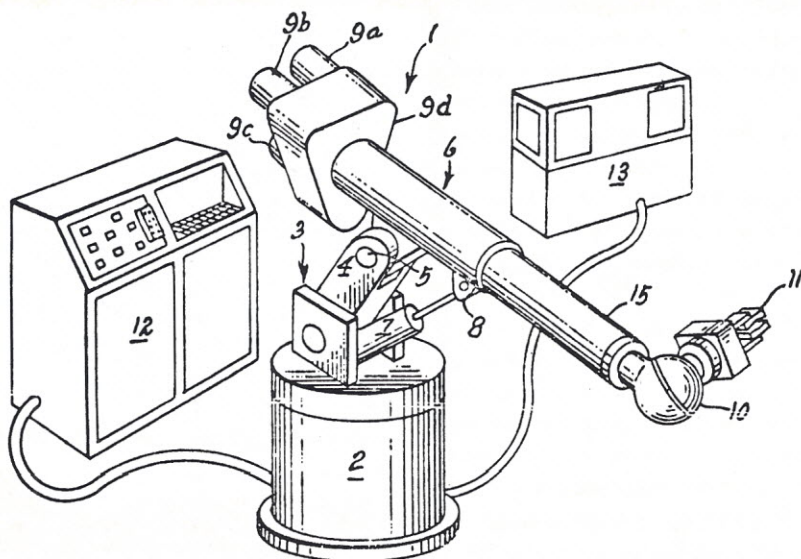


Figure 9. The Cincinnati Milacron 3-Roll wrist attached to the original hydraulic robot.

It can also continuously rotate the tool plate through 360 degrees. Using double preloaded bearing throughout its construction helps to make it extremely precise, giving the robot a positioning error of plus or minus .020 index.

This rugged wrist has a sealed, solid, metal housing filled with oil. It is very efficient mechanically because of the close proximity of the tool plate to the axis that drives it. The wrist has an internal passage for pressurized air to power a gripper or other end effectors, eliminating outside air supply tubes.

The wrist cannot be back-driven, thus losing a valuable programming method. As with the NASA anthropomorphic wrist, a considerable dwell time occurs when the wrist moves through certain positions.

Future Trends and Design Criteria in Wrist Actuators. I believe that a mechanical wrist which can be driven remotely is the way of the future. Larger, more powerful, drive sources can be employed if they are removed from the wrist.

The capability to back-drive the wrist for manual on-line programming is a desirable feature. Back-driving allows fast, easy programming for operators who may not be skilled in computer keyboard programming operations.

A mechanical wrist is inherently safe for work environments in which there

is danger of explosions. These situations require that inherently explosive-proof drive sources, such as hydraulic motors or hydraulic cylinders, be used.

Placing the pitch and yaw axes as close to each other as possible for mechanical efficiency and overall wrist compactness is important. This is a major problem with hydraulic wrist actuators. Keeping the tool plate close to the pitch and yaw axes further increases compactness and efficiency and gives

proportionately greater wrist strength and precision.

The more range of motion of the pitch and yaw axes, the larger the working volume and therefore, the more useful and versatile the wrist. The large working volume and continuous tool plate rotation achieved by NASA and Cincinnati Milacron are features that should become standard and be offered in wrists of the future if the manufacturer wishes to remain competitive.

Having as few parts in the wrist and having them play as many roles as possible is a useful goal. Clever use of cams, gears, linkage, ball-and-socket joints, or perhaps universal-joint concepts will accomplish this. The Flexiarm wrist is an example of a wrist using rather exotic components.

When using gears in the wrist, have as few meshes as possible to decrease backlash and achieve a speed reduction with every mesh so that there is maximum drive-shaft rotation or linkage movement for every degree of wrist movement. Doing this increases the power and precision that can be transmitted through the driving means.

A sealed, solid housing, as the Cincinnati Milacron 3-Roll Wrist has, seems ideal for ruggedness, low maintenance, and long life. A flexible covering would seem to be unsuitable in

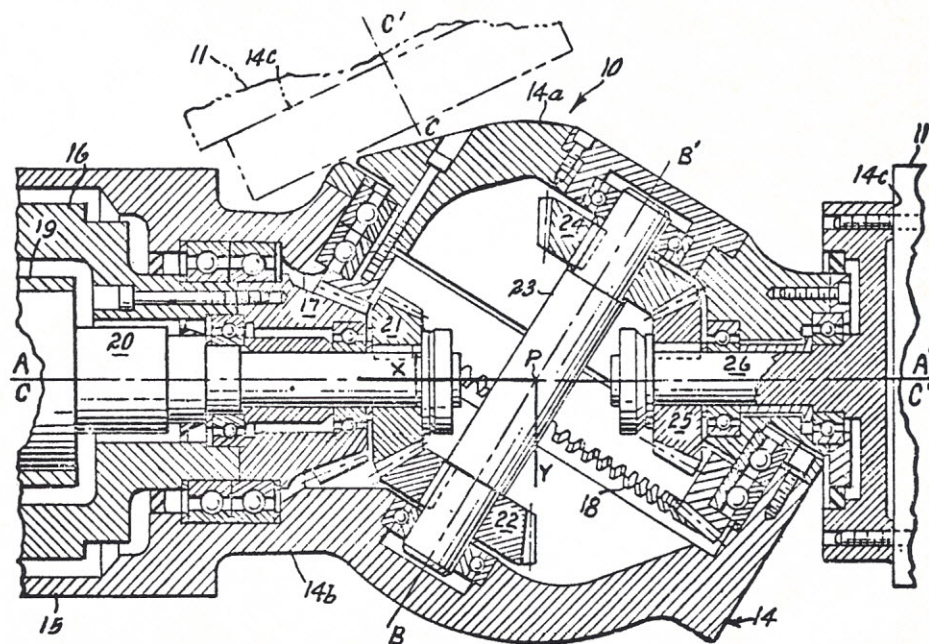
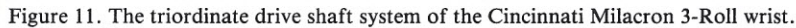


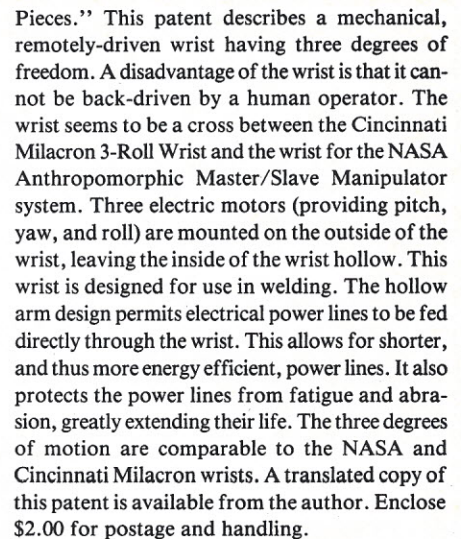
Figure 10. A cross-sectional view of the Cincinnati Milacron 3-Roll wrist in the top: straight bottom: rotated position.



There are many ways to transmit power from the drive source to the wrist. The triordinate shaft system that Cincinnati Milacron uses in their 3-Roll Wrist is compact and conveys the rotary motion from the motors to the wrist precisely. Push-pull rods operating in linear modes, such as the Flexiarm uses, is another method. ASEA Robots also use push-pull rods but in a sophisticated four-bar linkage arrangement in which the rods operate in a cranking motion. Flexible steel cables have been used by

NOTE: Copies of U.S. patents may be ordered from: Commissioner of Patents and Trademarks, Washington, D.C. 20231. Enclose \$1.00 per patent.

Bisiach, Luciano. *German Patent 27-52-236.* Issued July 31, 1980. "Tool Head for Working Machines, Specifically for Holding Welding Tongs or Lamps for the Welding of Work-



Flatt, Dr. Adrian E. "Influence of Wrist Pathomechanics on Hand Functions," *AM 14659*, University of Iowa. This article analyzes the kinematics of the human wrist; that is, its motion and the interaction of the bones, tendons, and muscles.

Moritada, Niitu, et al. U.S. Patent 3,784,031. Issued January 8, 1974. "Machine for Performing Work." This mechanical wrist actuator provides three degrees of freedom but cannot be back-driven. The motors are placed away from the arm itself. Three rotating, parallel drive shafts transmit power to the wrist mechanism. The mechanism itself consists of a group of bevel gears held by two frames. These gears translate the drive shaft's rotary motion into a pitch motion and roll motions. Yaw motion is achieved through the rotation of the entire wrist in a manner similar to that of the Cincinnati Milacron 3-Roll Wrist.

Rosheim, Mark E. *U.S. Patent 4,194,437*. Issued March 25, 1980. "Hydraulic Servo Mechanism." This back-drivable, directly-driven, hydraulic pitch and yaw actuator consists mainly of a ball-and-socket joint. The ball has two perpendicular grooves machined in it. The ball grooves seal against the socket and act as two hydraulic cylinders which drive the arm attached to the ball in pitch or yaw motion.

Rosheim, Mark E. *U.S. Patent 4,296,681*. Issued October 27, 1981. "Fluid Driven Servo Mechanism." This patent covers improvements

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JULY/AUGUST 1982: The Microbot Teachmover; Some Notes On the Rhino XR-1 and Minimover 5; Patent Probe; Use Your Apple As a Robotics Development System; IBM Robots; Adapting A Speech Synthesizer; Constructing An Intelligent Mobile Platform: Part I.

SEPT/OCT. 1982: Roving Robots, Report on SIGGRAPH '82; Patent Probe No. 4,221,997; Constructing an Intelligent Mobile Platform: Part II; The Physics of One-Legged Mobile Robots.

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to patent 4,194,437. See above.

Anon. "Rotary Actuators Welcome Tough Assignments," *Actuator Systems*, March 1981, pages 16-23. This article describes the Helac rotary vane actuator which could be used to make a compact wrist actuator with three degrees of freedom. The Helac's rotary motion is achieved by the use of reciprocating pistons. Helical splines convert the reciprocal motion into rotary motion. A copy of this issue is available for \$3.00 from *Actuator Systems*, Box 12901, Overland Park, Kansas 66212.

Stackhouse, Theodore Hahn. *U.S. Patent 4,068,536*. Issued January 17, 1978. "Manipulator." This patent describes a remotely-driven, mechanical wrist actuator. The wrist, which cannot be back-driven, is controlled by three concentric drive shafts which terminate in the spherically-shaped wrist mechanism. It is compact, rugged, and has a large range of motion. **Stauffer, Robert N.** "The DeVilbiss-Trallfa Spray Painting Robot," *Robotics Today*, February 1982, pages 81-82. This article reviews the DeVilbiss paint spraying robot and briefly describes the original direct-drive hydraulic wrist and the Flexiarm, a remotely-driven mechanical wrist actuator.

Totsuka, Hisao. *U.S. Patent 3,739,923*; June 19, 1973. Manipulator. Two parallel rotating drive shafts drive this remotely driven, back driveable, pitch and roll wrist. A bevel gear system in the wrist translates the drive shaft's rotary motion to a bending pitch motion and rotary roll motion. This patent seems to be the descendant of patent No. 3,784,031 Moritada, Niiu, et al item No. 5 in this bibliography.

Wells, Fredrick E. *U.S. Patent 3,631,737*; Jan. 4, 1972. Remote Control Manipulator for Zero Gravity Environment. A remotely driven back driveable pitch and yaw actuator. This actuator is driven by a complicated system of cables which are connected to several universal joints to create a great range of pitch and yaw motion.

Wells, William M. *U.S. Patent 4,045,958*; Issued September 6, 1977. "Multi-Directional Positioner." This is a direct-drive, back-drivable, pitch and roll hydraulic actuator. It consists of a ball-and-socket joint. The ball has one groove machined in it which interacts with a piston anchored in the bottom of the socket to give pitch motion. Roll motion is achieved by two pistons anchored in the ball's equator. These pistons interact with two grooves in the socket to produce roll motion.

Vykukal, Hubert C. *U.S. Patent 3,405,406*. Issued October 15, 1968. "Hard Space Suit." This patent describes an improved space suit. The suit's joints are of interest to wrist actuator designers. The following patent (4,046,262) describes further developments of this concept.

Vykukal, Hubert C. et al. *U.S. Patent 4,046,262*. Issued September 6, 1977. "Anthropomorphic Master/Slave Manipulator System." This patent develops the hard space suit by mounting electric motors in the space suit to drive the joints. This patent also describes master/slave control of the robot by placing a man in an identical suit, with his motions automatically mimicked by the robot space suit.

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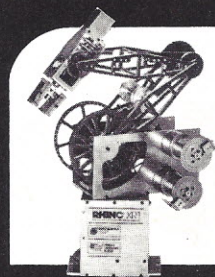
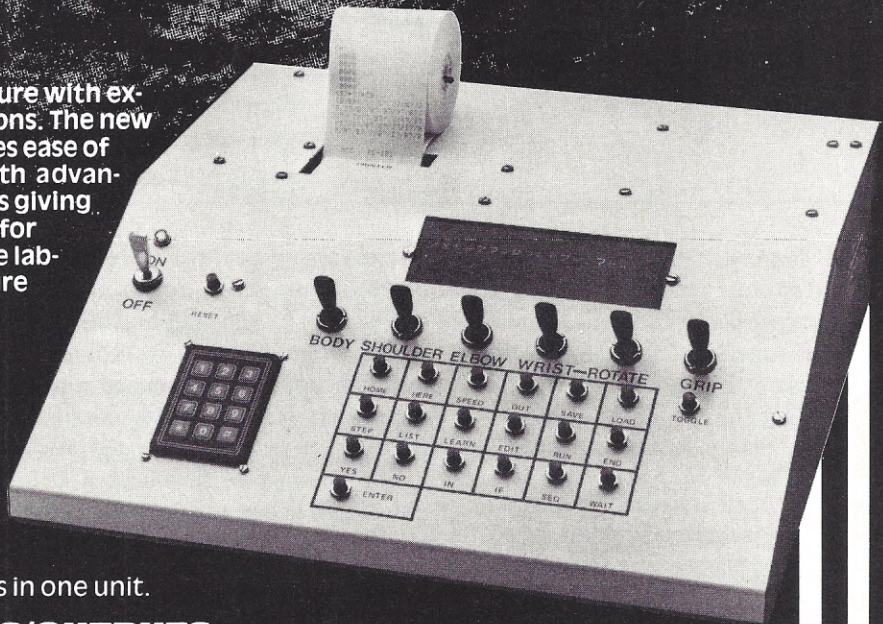
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PATENT PROBE

Heating Apparatus Having Voice Command Control

Russ Adams
3008 Mosby Street
Alexandria, Virginia

The first two Patent Probes dealt with inventions which fit the definition of robots propounded by the Robot Institute of America. The Institute defines a robot as:

A reprogrammable multifunctional manipulator designed to move material, parts, tools or specialized devices, through variable programmed motions for the performance of a variety of tasks.

Both expert and layman are inclined to accept this definition — It needs an arm!

In my opinion, such a definition is far too restrictive. I prefer the definition found in *The Random House College Dictionary*, Revised Edition. They define a robot as:

Any machine or mechanical device that operates automatically with humanlike skill.

It is the machine's intelligence, not its appendages, which ranks it in Genus Robotica.

I believe that the ambulatory home robot is an inefficient application of robotics for the home. A set of intelligent home appliances placed throughout a computer-controlled house would be far more efficient.

One such intelligent home appliance is that which falls under U.S. Patent number 4,340,800, issued July 20, 1982 to Shigeki Ueda and Teruhisa Takano of the Matsushita Electric Industrial Company located in Kadoma, Japan (see figures 1 and 2). The invention, titled "Heating Apparatus Having Voice Command Control Operative in a Conversational Processing Manner,"

relates to a microwave oven which the operator controls by spoken commands rather than by pushing buttons.

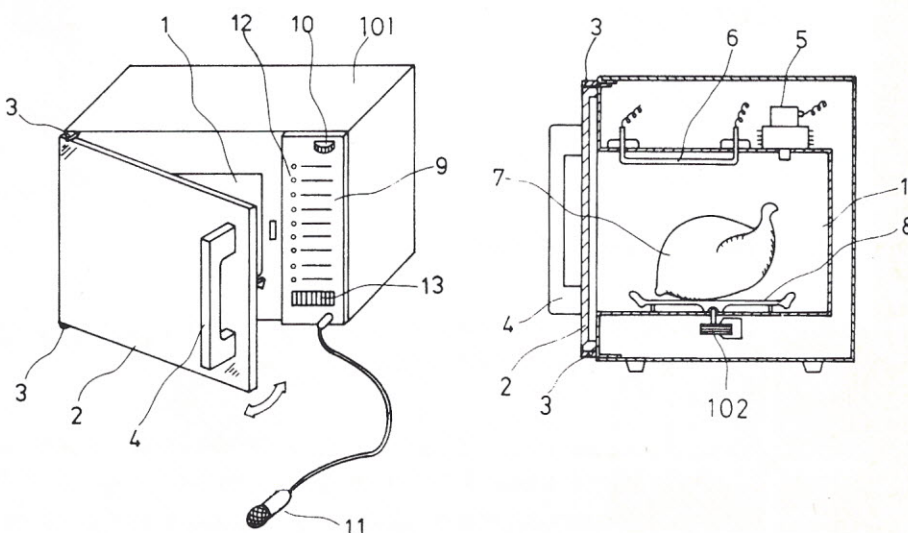
Many modern microwave ovens require an operation sequence which is specific to the food being cooked. If frozen meat is to be defrosted, for example, it must be first heated at low power, left to stand, and then heated at high power. In addition, the period of time of each stage of the defrosting cycle varies with the weight of the meat. Such a complex heating sequence normally requires entering the time and power through a keyboard. The keying operation can be quite complex and is therefore prone to error.

One attempt to reduce the complexity of data entry used sets of cooking cards, each with a magnetic band on which the data was stored. These cards were inserted into a card reader built into the oven, and the data was read. This solution had its problems. The cards

were sometimes misread with damaging results to both the food and the oven mechanism. The cards were also easily lost or misplaced.

The unique interactive voice control system of Ueda's and Takano's invention simplifies the oven programming process. The inventors recognized that the present state of voice recognition technology does not always provide accurate interpretation of spoken commands. This lack of accuracy is even more of a problem when more than one operator will be giving the commands. With their invention, spoken commands are used in a reliable microwave oven control system. The operator can confirm the correct interpretation of the spoken command before the oven executes it.

After the operator gives the command, the system interprets it and finds the best match among its prestored list of command voice patterns. The

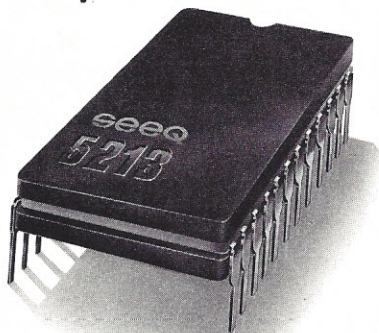


Editors' Note: Figure numbers are those found in the original patent document.

Figures 1 and 2. A perspective view of the intelligent microwave oven of Ueda and Takano.

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machine then outputs a synthetic voice which makes a statement or asks a question related to the interpretation of the command.

From the contents of the statement or question, the operator can determine if the oven correctly understood the command and verbally respond to the statement or question. The oven apparatus then interprets the response and either proceeds with the command action or cancels the action and awaits another command. By such a two-step process, the problem of an incorrectly interpreted command causing damage is reduced to a minimum.

The control system consists of a voice input device, such as a microphone, and a voice pattern analyzer which converts the analog voice signal to a digital representation. The digitized output of the analyzer is stored in a memory buffer. The system contains a reference voice pattern memory which stores a set of voice commands. A recognition circuit compares the pattern in the buffer memory with the reference patterns and produces an output when the affinity is above a preset level. A voice synthesizer system responds to the output of the recognition circuit and generates a verbal question or statement related to the interpreted command. A main command circuit controls the sequence of operation of the apparatus.

The Algorithm. The cycle of operation proceeds through four modes (see figure 13). The first is the voice recognition mode, which receives a voice command and processes it. The second is the voice synthesizing mode in which a voice output signal is generated to ask the user to speak a second voice command. The third is a second voice recognition mode in which only a limited number of responses to the synthesized question are recognized. The fourth is an action-taking mode in which the oven executes the command or cancels it.

When the oven is switched on, the device enters the first recognition mode and waits for any voice command to be received by the microphone. If the command "roast beef" is spoken, for example, the sound is subjected to pattern

analysis. The recognition circuit performs an analysis of all expected commands and produces a degree-of-correlation signal. When this signal exceeds a set level, the voice synthesizer is activated to produce a voice response. In this case, the response would be "medium?" which has relevance to the command "roast beef." During voice synthesis, the recognition circuit is turned off so it will not be activated by the synthesized voice response.

After the synthesized question or statement has been generated, the ap-

paratus enters the second voice recognition mode. In this second stage of recognition, the oven recognizes only a limited number of responses. In our example, the apparatus expects the operator to say either "yes," "well-done," "rare," or "pardon?" Commands like "defrosting" or "hamburger" are not recognized.

If the second-level commands "yes," "well-done," or "rare" are recognized, the necessary heating sequence is preset, and the apparatus waits to hear "start" before carrying out the command. If

Continued on page 52

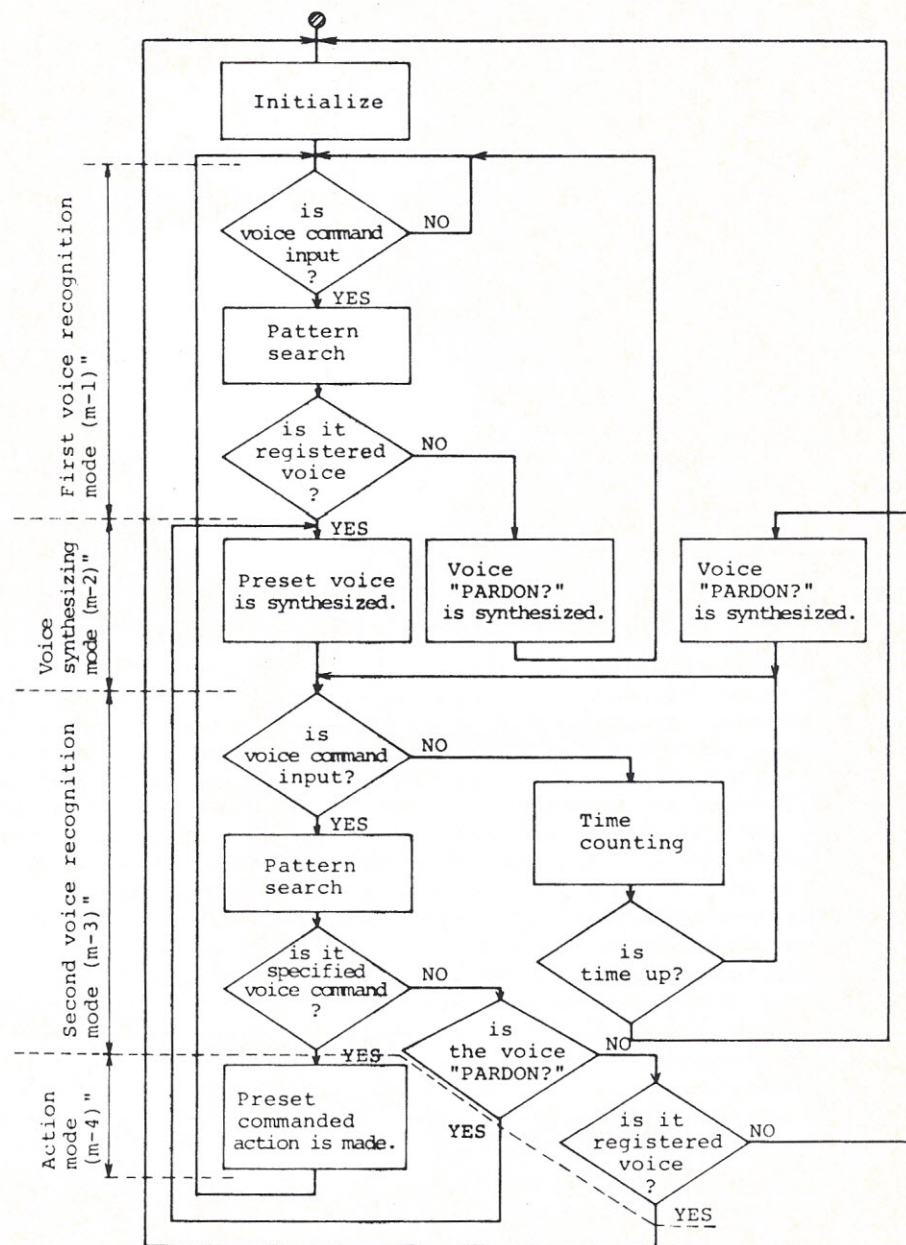


Figure 13. Program flowchart detailing the general steps in interpreting and executing the voice commands.

A MICROCOMPUTER BASED, REAL-TIME ROBOTICS SYSTEM

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Computer Science Department
University of Wyoming
Laramie, Wyoming 82071

The problems associated with making robots interact with people in a human fashion are vast. Consider the final goal of such interaction to be the construction of a robot with all of the sensory input of a human being (sight, hearing, touch, smell, and taste).

The robot must be capable of manipulating objects in its environment in a manner that involves understanding input from each of its sensors as well as planning sequences of actions. This ultimate goal, while difficult, can be approached in stages if the software is constructed in a manner similar to building a pyramid.

The top block of the software pyramid is the ultimate goal of the intelligent machine. This goal is supported by many other pieces, or subgoals. Such support software includes programs that gather data from the sensors, extract features (characteristics) from the sensory data, recognize certain sensory inputs by associating new inputs with previous experiences, and plan and execute sequences of actions based on the state of the robot's world and the desired state at some future point.

This article describes a working set of software that accomplishes these four subgoals in a very restricted domain known as the blocks world. The approach should be viewed primarily as a model for the modular design of an intelligent robotics system. Any one of the pieces can be modified to alter the performance of its particular function.

The system is used in the artificial intelligence course at the University of Wyoming as a model for building soft-

ware that incorporates feature extraction, pattern recognition, and action planning. The top goal in the particular software is the ability to command verbally a robot arm that can visually examine its environment.

The Robot System Hardware. A portion of the blocks world is shown in photo 1.

The robot arm is a Minimover-5, manufactured by Microbot, which is controlled by six stepper motors. The arm is radially jointed at its base for rotation, at its shoulder and elbow for extension, at its wrist for pitch and roll,

and at its hand for opening and closing. It has a single sense switch to detect if the hand is grasping an object.

The eye of the robot is a vidicon (television camera) connected to an image digitizer. This digitizer gives the robot a matrix image of its world. The matrix is 256 rows by 256 columns. Each matrix element (pixel) is a number representing the light intensity at a point in the scene. These values range between 0 (black) and 15 (white).

The robot ear is a microphone connected to a speech digitizer. The speech digitizer provides four values. The first three values are numbers proportional

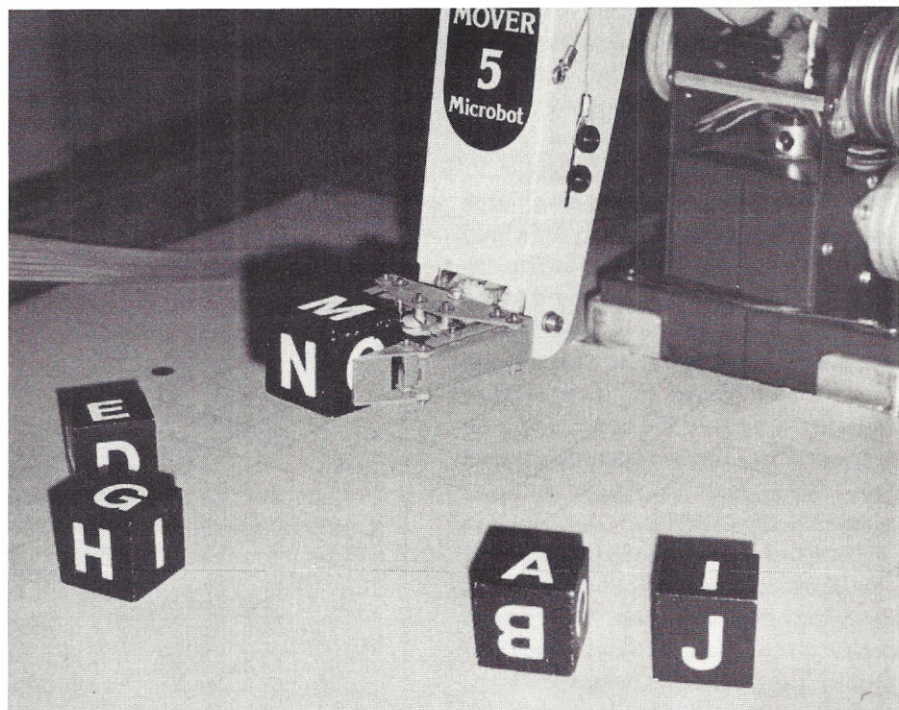


Photo 1: A view of the blocks world. The Minimover-5 robot arm moves the high-contrast blocks around on the white table top. The blocks are viewed by a television camera connected to a 256-by-256 pixel video digitizer. The entire system is controlled by a Cromemco System 3.

to the amounts of energy in the frequency ranges 150-900 Hz, 900-2200 Hz, and 2200-5000 Hz. The fourth parameter is a value proportional to the number of times the speech waveform crosses a certain reference voltage/unit time.

Visual Information Processing. A single scan of the entire viewable area (about 30 by 40 centimeters) is made during the visual processing phase. During the first scan pass, the system merely attempts to locate candidate pixels that could be part of a larger object. The initial scan examines the grid (pixel values) formed when the viewing area is divided into approximate 1.5-centimeter units. The scan tests each grid element to determine if it is less than some threshold value. Since each block (exclusive of the letter painted on it) is quite dark relative to the table top, this test roughly locates the blocks. If the test condition is satisfied, that pixel is a candidate for inclusion in a larger object region (block) during the second pass.

Once an object candidate pixel is identified, a search window around that pixel is examined. The size of the window is variable. In general, the window size is based on the maximum size of the objects that are expected in the scene. The object boundaries that may exist within the window are sought by scanning each row of pixels from left to right and then from right to left.

Negative gradient transitions of large magnitude (going from a very light area to a very dark one) are used as the criteria for defining the outer edges of the objects. It is important to note that, in this initial configuration, two objects must not be placed so close together that they appear in the same candidate scan window. The information gleaned from this process is a set of boundary pixels for the objects.

The third pass seeks the boundary of the character within the previously described object region. The object region is scanned left to right and right to left, like the second pass, with high, positive gradients as the boundary for the (light colored) letter on the (dark) block. Figure 1 illustrates the boundaries derived in the first three passes.

Feature Extraction. At this point, the feature extraction phase proceeds. The primary purpose of feature extraction is deriving from the data a set of characteristics that is representative of that particular object. For example, the letter I is “thin” and the letter O is “round.” Both thinness and roundness can be expressed as mathematical quantities using many different techniques. One technique is the use of second central normalized moments.

Suppose you construct a letter I and a letter O from pieces of steel. Assume that the letter I is one meter in length and 10 centimeters wide and that the letter O is a perfect circular ring 10 centimeters wide and one meter in diameter. Consider what happens if you rotate the I about its two main axes. It takes considerably more effort to rotate the I around the axis with the shorter length than it does to rotate the I around the axis with the greater length. The

amount of effort required is proportional to a quantity called the second central moment.

For the letter I, the maximum second central moment is very large compared to the minimum second central moment. For the letter O, on the other hand, the moments are the same. Figure 3 illustrates the second central normalized moments for various letters of the alphabet that were used in the robot's world. The minimum moments are on the bottom axis, and the maximum moments are on the vertical axis. This chart illustrates a two-dimensional "feature space" and is the basis for the visual recognition that follows. The class that is chosen as the identity for an unknown object is the class that is closest to the unknown in the feature space. If you are interested in the formal definition of the mathematical computations involved in the feature extraction process, refer to *Pattern*

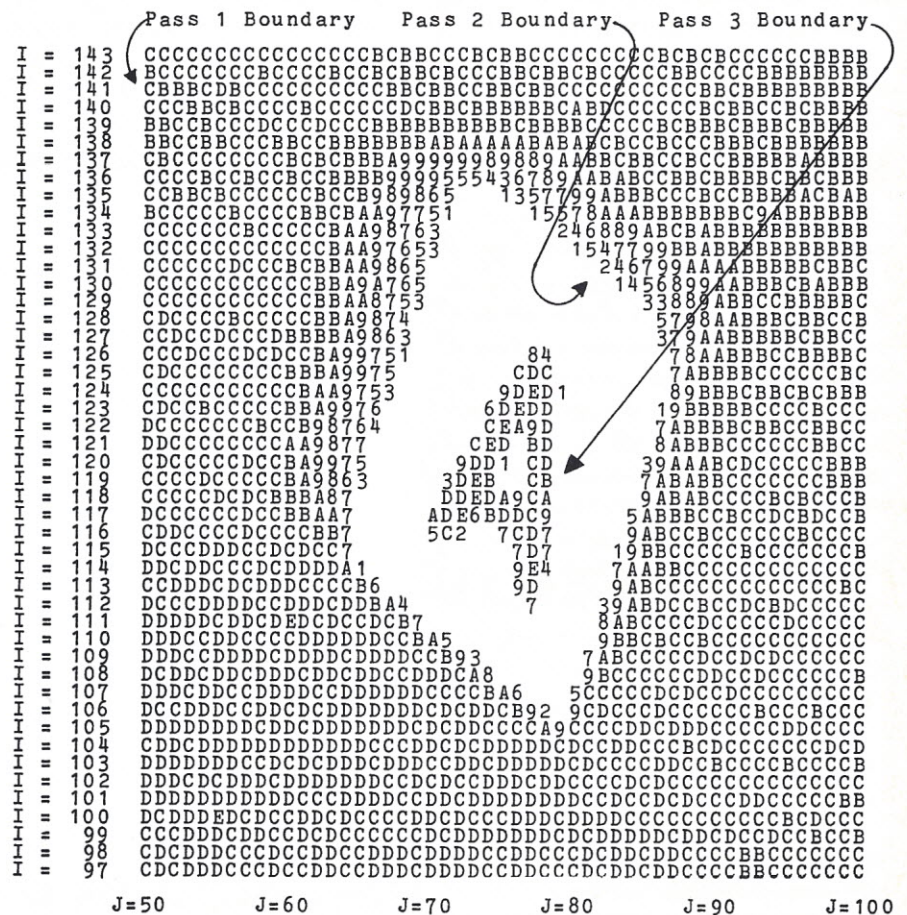


Figure 1: Boundaries derived in passes 1, 2, and 3 for the letter A. The varying intensity levels are shown with relative hexadecimal values.

Recognition Techniques in Cloud Research. (See Reference p. 33)

The second central normalized moments CM02P and CM20P are computed for the bounded character as shown in the equations below.

Others such as H and N, however, are very close together in the feature space and are easily confused. Thus, second central normalized moments are generally not sufficient for proper letter identification. Other features

Equations

$$A = \sum_{i=B(1)}^{B(2)} \sum_{j=b(i,1)}^{b(i,2)} g(i,j)$$

$$CN_{pq} = \frac{1}{A} \sum_{i=B(1)}^{B(2)} \sum_{j=b(i,1)}^{b(i,2)} i^p j^q g(i,j)$$

$$CM_{pq} = \frac{1}{A} \sum_{i=B(1)}^{B(2)} \sum_{j=b(i,1)}^{b(i,2)} (i - CN_{10})^p (j - CN_{01})^q g(i,j)$$

$$\theta = \tan^{-1} \left[\frac{-2 CM_{11}}{CM_{20} - CM_{02}} \right]$$

$$CM'_{20} = \left(\frac{CM_{20} + CM_{02}}{2} \right) + \left(\frac{CM_{20} - CM_{02}}{2} \right) \cos 2\theta - CM_{11} \sin \theta$$

$$CM'_{02} = (CM_{20} - CM_{02}) - CM'_{20}$$

CM'20 and CM'02 are the maximum and minimum second central moments that define the feature vector for each character. Theta (θ) is the angle of orientation of one of the letter's principal axes. A more complete description of the derivation for these formulas is given in *Pattern Recognition Techniques in Cloud Research* cited in the list of references on page 33.

The values B(1) and B(2) are the indices of the bottom and top edges of the pass three boundaries. The values b(i,1) and b(i,2) are the indices of the left and right edges of the pass three boundary on line i. The grey-scale value of the pixel at row i, column j is represented by g(i,j).

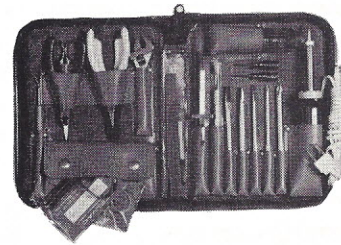
The ordered pair (CM02P, CM20P) is treated as a two-dimensional feature vector. It is compared with the average feature vectors of previously learned samples of randomly oriented blocks that have been presented in a training session. The letter with the minimum Euclidean distance from the unknown sample is chosen as the class with which the unknown letter should be associated.

This method alone is insufficient to properly recognize a letter. Figure 2 shows that certain letters are relatively isolated in the feature space (I, A, E, O, for example) regardless of orientation.

beyond the scope of this article are necessary for complete separation of classes.

After the feature information is extracted from the digitized picture, the location and orientation of the block is recorded. The direction of the maximum normalized second central moment is taken to be the axis of the block with which the robot hand will eventually align. This is a reasonable constraint for cases in which the letters have one axis of bilateral symmetry (for example, A, B, C) that is perpendicular to two sides of the block. It causes problems, however, with letters such as F or

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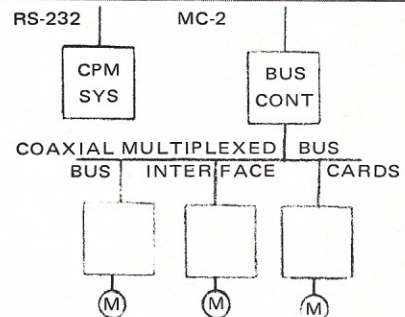
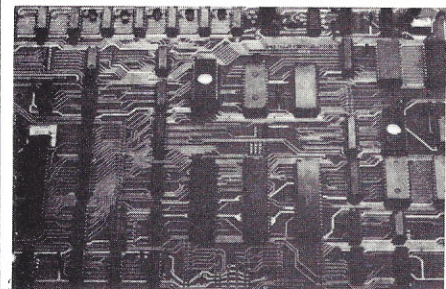
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CIRCLE 6

N. The location of the first order moments (center of gravity) of the block boundary is recorded as being the *approximate* set of coordinates to which an open hand should be positioned prior to grasping the block at a later time. As you will see in the later section on robot control, the actual position is altered as a result of the robot sensing the block while closing the hand. The recorded coordinates are relative to three calibration markings that permit correlation of pixel coordinates and robot table coordinates.

Speech Processing. The robot derives its verbal input from three bandpass filters and a zero crossing detector.

Figure 3 shows typical data plots for the words "stack," "erase," "cancel," "terminate," and "relearn." The horizontal axis for each graph is the number of 10ms time intervals since the beginning of speech. The vertical axis is a value proportional to the energy or number of crossings during the interval.

As an example, consider the plots for the word "terminate." The zero crossing detector notes two sharp spikes that occur at the "t" sounds in the frame. The low-pass filter contains the most information (since the speaker had a low voice), with three prominent peaks occurring during the three syllables of the word. The word "erase," on the other hand, shows only one peak in the low

frequencies since the "e" sound is in the higher range. Figure 4 shows that words which sound similar (hello, mellow, and yellow) also have similar data plots. For this reason, dissimilar sounding commands were chosen to maximize the likelihood of correct recognition.

All spoken commands must begin with a verb and end with a period. The speaker acknowledges that all words in the sentences have been properly recognized by saying the word "period." Once the word "period" is recognized, the robot starts to plan its actions based on the other words in the sentence. If words are incorrectly recognized, the speaker can say "erase" to cause the robot to forget the most recently spoken words in the sentence. The entire sentence can be deleted by the word "cancel." The word "relearn" causes the robot to enter training mode. The robot prompts the speaker to speak improperly learned words.

The block manipulation commands are designed to facilitate any valid construction of blocks on the table. The types of commands that the interactive robot can process are illustrated by the following spoken phrases:

- STACK — Build a stack of all blocks, with the first block found on the bottom and subsequently found blocks higher in the stack.
- LIFT BLOCK (letter) — Grasp the block with the specified letter on it and hold it until another command is given.
- LOWER ONTO BLOCK (letter) — Take the currently grasped block and place it on top of the indicated block.
- LOWER ONTO THE TABLE — Get rid of the block being grasped by placing it at a clear spot on the table.
- ERASE — Erase the last word recognized in the sentence.
- CANCEL — Cancel the entire sentence.
- RELEARN — Relearn a word (usually one that is incorrectly recognized).
- TERMINATE — Stop processing and return control to the operating system (after getting rid of any blocks that may be in the gripper).

The speech recognition system uses template matching, in which known samples are compared against each spoken word. Template matching is analogous to measuring the closeness of one waveform to another. In figure 4, if the (vertical) difference at each point

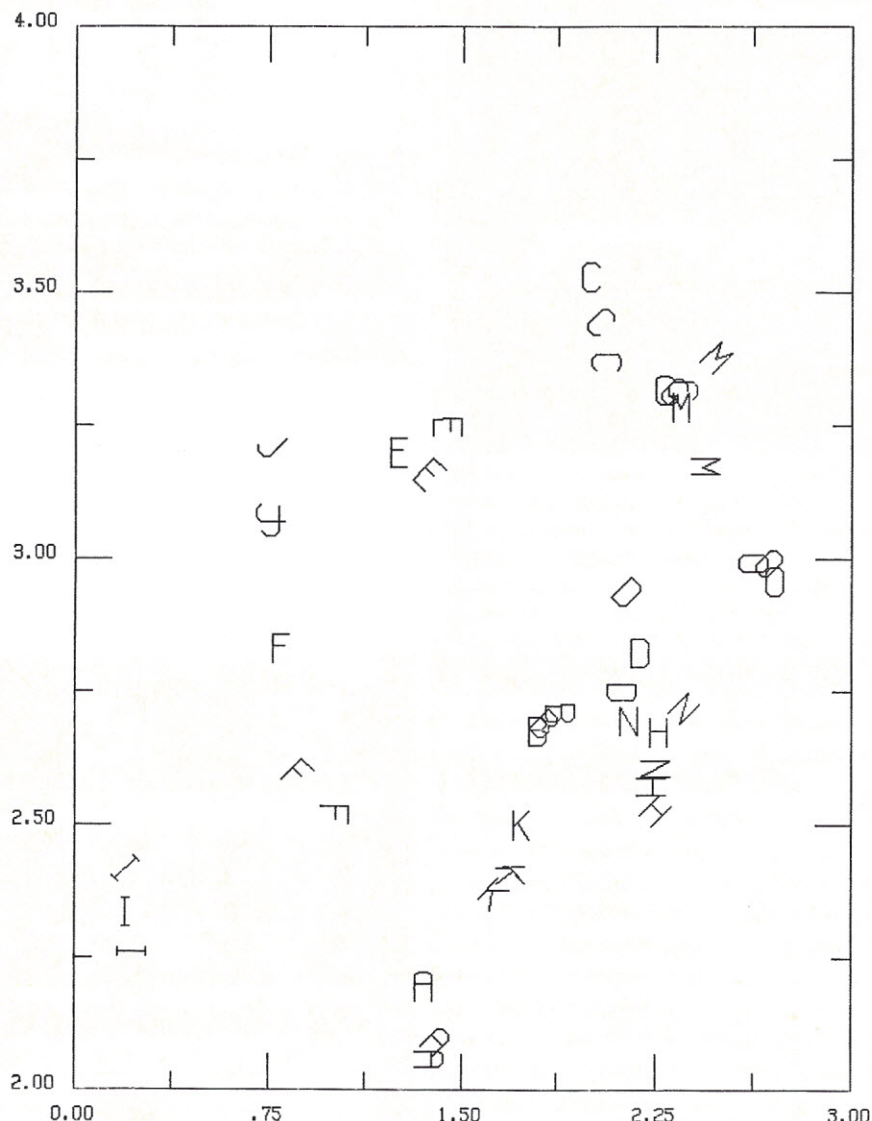


Figure 2: The two-dimensional feature space for the letters A through O, with orientations at 0, 45, and 90 degrees.

in time is computed between an unknown sample of speech and stored, known words, then the unknown should have a minimal difference from the known with which it should be associated. For example, the words "erase" and "terminate" would match poorly with each other since their waveforms differ significantly in each of the four parameters considered. More formally, the template with the minimum difference $D(k)$ is chosen as the identity of the unknown speech sample.

$$D(k) = \sum_{i=1}^{NS} \sum_{j=1}^{NP} |T(i,j,k) - U(i,j)|$$

where: NS is the number of speech samples

NP is the number of speech parameters (=4)

$T(i,j,k)$ is the i th sample of parameter j for template k

$U(i,j)$ is the i th sample of parameter j for the unknown phrase

Robot Command Processing. Once a verbal command is recognized, the robot arm control software attempts to execute the specified action. After the visual processing pass is completed and the verbal command sequence is initiated, the system does not process visual information again. Thus, there must be internal representations of the high-level structures (blocks) in which positions and orientations are updated as the physical structures are manipulated by the arm. The consequences of various actions are best illustrated by a sample conversation in which the blocks on the table are A, B, and C.

1. STACK causes the stack consisting of A, B, and C (bottom, middle, and top, respectively) to be constructed. This command is illustrative of the manner in which the true location of blocks is forced by the hand. Before B is lifted to be placed upon A, the hand plans a move in which it grasps block A such that the hand is aligned with the major normalized second central moment axis. Following the first grasp (which is terminated when the gripper switch activates), the hand opens fully, rotates $\frac{1}{4}$ turn (90 degrees) and grasps the block about the other axis. In the process of grip-

ping the block about its two major axes, the block usually shifts slightly in each direction, since one side of the hand will probably come in contact with the block before the other due to the fact that the initial position of the block is approximate. This action compensates for inaccuracies in position that may have arisen due to the inclusion of short shadows in the boundary of the object.

Following the positioning of block A, block B is grasped in a similar manner, lifted and placed atop block A. Typical errors in this action are less than 1.5 mm between the faces of the blocks as they rest on one another. Finally, block C is put on top of the entire stack.

2. LIFT BLOCK B causes block C to be grasped (since it is on top of block B), lifted, and lowered onto a vacant spot on the table. This action is followed by the grasping and lifting of block B.
3. LOWER ONTO C causes two stacks to be created: a single block stack consisting only of A, and a two block stack consisting of B on top of C.

Although the robot does not visually examine its environment again, it stays fully aware of the state of the world by updating location tags associated with each object seen in the visual pass. It does this by recording the

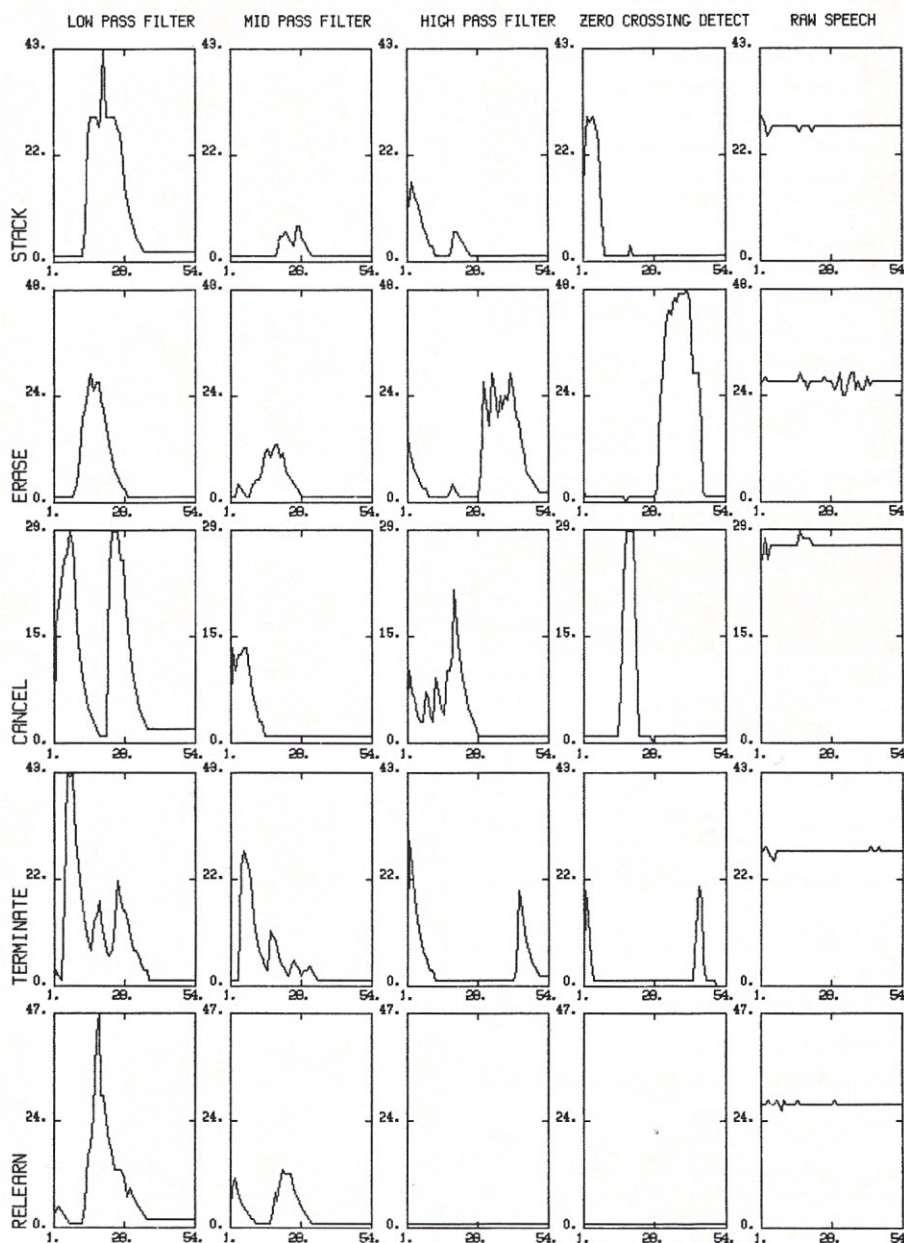


Figure 3: The template plots in each of the speech digitizer parameters for the words stack, cancel, terminate, and relearn.

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This planning method is quite similar to Winograd's CLEARTOP and GET-RID-OF procedures.

The robot system yields relatively good results for single speaker/trainer experiments and demonstrates the utility of modular design in artificial intelligence software. It also illustrates typical problems that robot system designers encounter. The planning capabilities in the operational domain are quite adequate; it is virtually impossible to cause the robot to err in its planning. Planning faults do occur when the state of the world is unexpectedly altered after the visual processing phase. A typical cause of such an error is the hand's inadvertently dropping a block, in which case it no longer knows the location of all objects in the scene.

Response time for the image processing phase depends on the number of blocks in the scene and the complexity of the characters on each block. The average processing time is approximately 10 seconds per block. Speech

recognition is less than one second per word for a 20 word vocabulary. The processing is performed on a Cromemco System 3, which contains a Z80 processor running at 4 MHz. The primary processing limitations are related to processor speed, disk access rates and the speech digitization and recognition process.

As previously pointed out, similar words do not show up in digitized data as differing significantly for recognition purposes. I have experimented with context-sensitive methods in which the relationship of one word to others in the sentence is considered. The method used was implemented on a large mainframe (Cyber 170/760) and is impractical for the microcomputer system due to the processing speed and available storage needed by the algorithm.

The most significant performance improvement needed is the ability to continuously monitor the state of the robot hand with respect to the visual environment. Since only one visual pass

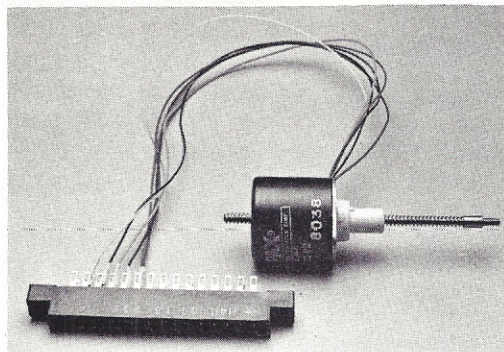
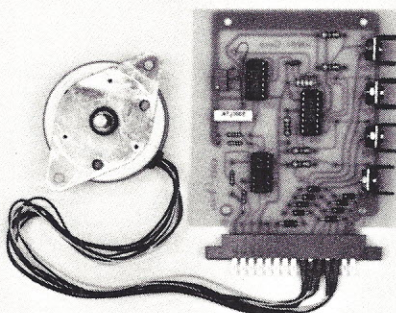
is made prior to the command phase, the robot does not know the state of the world as it moves objects about. If it drops a block, or inadvertently knocks into another one, its internal representation of the state of the world is incorrect. Continuous visual monitoring of the scene, however, would be prohibitive on the microcomputer. □

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Calendar

Continued from page 14.

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IEEE Robotics Conference

The Institute of Electrical and Electronics Engineers will provide a national televised conference on Robotics on December 7, 1982. Between 1000 and 1500 persons in various sites nationwide are expected to enroll, according to Barry Oakes, a member of the IEEE's Continuing Education Robotics Subcommittee.

The satellite broadcast course will focus on aspects of robotics to which electrical and computer engineers can most contribute — for example, robotics as a total manufacturing process. At the present time, there are dumb arms in the auto industry that weld; workers put the

two parts together and the machine arm welds the parts. A more advanced process would be a system that could distinguish the parts (classify them by size, weight, and color). The machinery for such a system would need sensing and dextrous movement abilities. Software and electromechanical engineers are necessary to develop such a system.

The five-hour course, from 11 a.m. to 4 p.m. Eastern Standard Time, will feature four speakers: James Albus of the National Bureau of Standards; Maurice Dunn of Unimation, Danbury, Connecticut; Michael Radeke of Cincinnati Milacron Inc., Ohio; and Thomas Sheridan of the Massachusetts Institute of Technology, Cambridge, Massachusetts.

Dr. Albus and Dr. Sheridan, scheduled as the morning speakers, will discuss the research and development aspects of robotics, particularly for advanced machines. In the afternoon, Mr. Dunn and Mr. Radeke, from two of the largest robot manufacturers, will show

movies and speak on the current uses of robots. The conference is designed to be evenly divided between robotics theory and applications. There will be telephones at each site so that participants can ask questions of the speakers.

Cities scheduled as IEEE sites are Boston, New York, Philadelphia, Pittsburgh, Washington, D.C., Atlanta, Chicago, Detroit, Minneapolis-St. Paul, Dallas, Houston, Orange County, California and San Francisco.

In addition to these sites, other IEEE Sections, universities, and corporations can buy into the program. Registration fees are \$125 for IEEE members and \$175 for non members, \$25 of which is applicable to IEEE fees if the non member wishes to join. Non-IEEE sites can rent equipment to receive the course for about \$1200.

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THE PHYSICS OF ONE-LEGGED MOBILE ROBOTS

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Part II: The Mathematical Description

While computer simulation of walking machine dynamics allows us to concentrate on the information processing problem, any physical walking robot must be equipped for sensory and motor functions. These needs present enormous challenges.

Sensory Requirements: Ideally, the "brain" of a walking machine would like its senses to provide complete knowledge of the machine's physical state at all times. This information includes height above the ground, vertical and horizontal velocities, angle of the leg and body with respect to the ground and with respect to each other, and compression of the spring in the leg. Some of this information is redundant; that is, one piece of information may help in the calculation of another. Yet, with available technology, designing a sensory system of reasonable cost which can furnish adequate state information to the controller is a difficult task.

Two approaches to sensory input can be taken. The more restrictive is to place sensors only on the machine itself. This goal must be attained before walking robots are able to locomote out of the laboratory on their own. On-board sensory devices which have been suggested include potentiometers for measuring the angle of the leg with respect to the body and angle of the leg with respect to the ground (when the foot is touching the ground), gyroscopes for inertial measurement of body angle, sonar range finders directed at the ground to measure body height above the ground, and optical encoding of the position of the sliding foot in the leg. In principle, these senses would provide direct or indirect measurements of all state parameters except horizontal velocity.

It turns out that for humans using a pogo stick visual feedback is very important. One role for vision is to gauge horizontal velocity in preparation for choosing a landing angle. The state of robotic vision is too primitive now to extract this information from a video TV signal in real time in a general visual environment. Use of specially painted backgrounds and floors might make the use of rugged on-board TV cameras feasible for measuring horizontal velocity or other state parameters.

More complete information can be gained by use of off-board sensors which may be too large or bulky

to be mounted on the walking machine itself, such as television cameras, laser range finders, photodetector arrays, lightweight wires, and innumerable other gadgets.

In practice, the information obtained from the various sensors is likely to be noisy, incomplete, and even contradictory. For these reasons, best use of the sensors may be made not by merely measuring data and handing it to the controller, but by performing some sophisticated interpretation and analysis of the raw sensory input. For example, it may turn out that the best way to measure height of the body above the ground is to use measurements from downward-looking sonar range finders, except during the landing phase of the hopping cycle, at which time the leg extension measurement should be used. In this way, internally stored knowledge of the hopping cycle might be important in interpreting sensory inputs. This speaks for rich interaction between sensory and controller functions of the walking machine, and a control method which maintains some sort of internal model of the walking process.

Motor Control: Once the controller has determined what physical actions are necessary to maintain balance, some sort of actuators must exert appropriate forces and torques as specified.

For the single-legged hopping machine, two modes of movement must be established. The first is rectilinear motion of the foot with respect to the leg and body. Unlike the perfect spring we can postulate in the leg of a computer-simulated pogo stick, a physical device will dissipate energy during the course of a hopping cycle which will have to be restored to the system continuously if constant hopping height is to be maintained. The second type of movement is the pivoting of the leg with respect to the body. This pivoting must be controlled while the pogo stick is in the air so that the leg will be at the correct angle when the machine lands.

It is desirable for a walking machine to use actuators with a high power/weight ratio so that large steps may be taken and so that movements may be made quickly in reaction to commands from the controller. By the same token, if the robot is to be completely self-contained and self-propelled, energy

storage devices of a high energy/weight ratio should be used. The size and weight of electric batteries pose major drawbacks for an electrically powered hopping machine. Alternatives include pneumatic piston drives and electric motors powered by an umbilical cord to an external power source.

Mathematical Corner

A one-legged walking machine proceeds through four phases during a hop cycle. These will be termed:

1. In the air
2. Air to ground (landing)
3. On the ground
4. Ground to air (takeoff)

Stages 2 and 4 are instantaneous events, while stages 1 and 3 are described by systems of differential equations which can be solved numerically. We will consider a pogo stick hopping in two dimensions, horizontal and vertical, as drawn in figure 1. The machine itself has two degrees of movement:

1. The leg pivots about the body; actuators connected to the body are able to apply a torque to the leg about the pivot point.
2. The foot slides along the leg; up and down forces are transmitted from the foot to the leg through a spring.

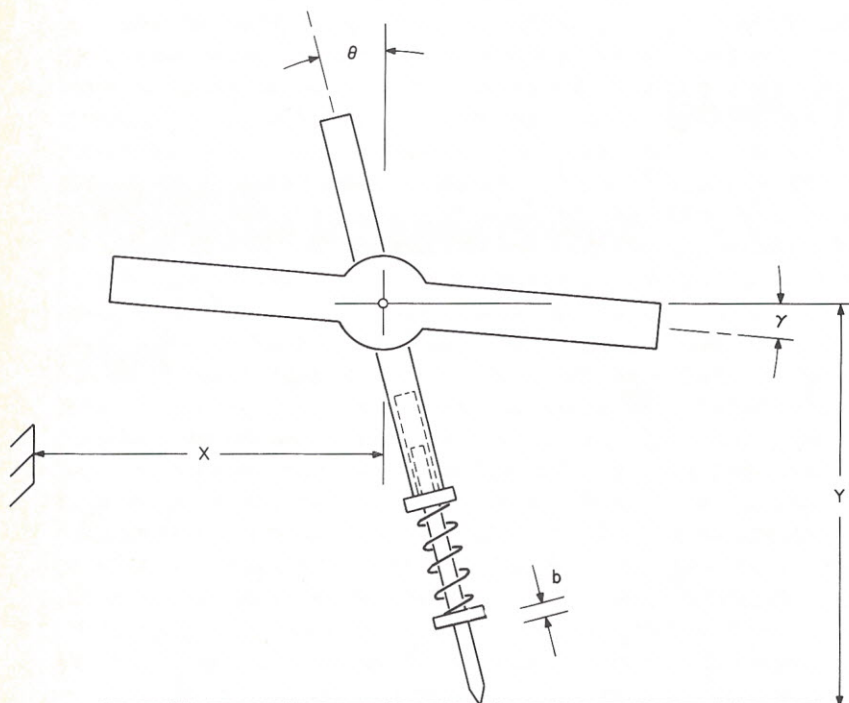


Figure 1.

The center of gravities of both the leg and the body are assumed to lie at the pivot point. Important fixed parameters of the system are:

MST	=	mass of whole pogo stick
GR	=	acceleration due to gravity
L	=	1/2 length of leg
IFTG	=	moment of inertia of leg with respect to ground

IPLP	=	moment of inertia of body with respect to pivot
MPL	=	mass of body
IFTPL	=	moment of inertia of leg with respect to pivot
MFT	=	mass of leg
K	=	spring constant of foot-leg spring
IPLG	=	moment of inertia of body with respect to foot

In addition, the positions, velocities, and accelerations of the pogo stick are described by the following variables:

x	=	horizontal position (measured at pivot)
$\dot{x} = x'$	=	horizontal velocity
$\ddot{x} = \ddot{x}'$	=	horizontal acceleration
y	=	vertical position (measured at pivot)
$\dot{y} = y'$	=	vertical velocity
$\ddot{y} = \ddot{y}'$	=	vertical acceleration
b	=	compression of spring
$\dot{b} = b'$	=	rate of change of compression of spring
$\ddot{b} = \ddot{b}'$	=	acceleration of compression of spring
θ	=	angle of leg with respect to vertical
$\dot{\theta} = \theta'$	=	rate of change of leg angle with respect to vertical
$\ddot{\theta} = \ddot{\theta}'$	=	acceleration of leg angle with respect to vertical
ϕ	=	angle of body with respect to horizontal
$\dot{\phi} = \phi'$	=	rate of change of body angle with respect to vertical
$\ddot{\phi} = \ddot{\phi}'$	=	acceleration of body angle with respect to vertical
τ	=	torque applied between leg and body

For computer simulation, assume no energy loss in compression of the spring. To perform a numerical integration, we will express the dynamics in terms of a system of first order differential equations:

$$\dot{q} = f(t, q),$$

where q is the set of state variables. Substitution of variables (primed variables) will be used when necessary to reduce all equations to first order.

Phase 1. In the air

The pogo stick takes off with some values for all of the above mentioned variables. The differential equations which describe their changes in time can be written down more or less directly.

$$\begin{aligned}
\ddot{x} = \dot{x}' &= 0 \\
\dot{x} = x' &= \text{horizontal velocity at previous takeoff} = \text{constant} \\
\ddot{y} = \dot{y}' &= -GR; \text{ acceleration due to gravity} \\
\dot{y} = y' & \\
\ddot{b} = \dot{b}' &= 0 \\
\dot{b} = b' &= 0 \\
\ddot{\theta} = \dot{\theta}' &= -\tau/IFTP; \text{ torque acting on foot} \\
\dot{\theta} = \theta' & \\
\ddot{\phi} = \dot{\phi}' &= \tau/IFTP; \text{ torque acting on body.} \\
\dot{\phi} = \phi' &
\end{aligned}$$

The torque parameter, τ , is specified by the controller. These equations are integrated numerically one time increment after another until the foot touches the ground:

$$y - L \cos \theta \leq 0$$

Phase 2. Air to ground

The mathematical transition of parameters for a simplified pogo stick upon landing is somewhat arbitrary and generally follows reasonable assumptions about conservation of momentum and continuity of positions and angles.

$$\begin{aligned}
V_{\text{LAND}} = \sqrt{\dot{x}^2 + \dot{y}^2} &= \text{total velocity at landing. This is broken into a linear component, } b', \\
\Phi = \theta - \tan^{-1}\left(\frac{\dot{y}}{\dot{x}}\right) &\text{ and a rotational contribution to } \dot{\theta}.
\end{aligned}$$

$$\text{set } \dot{b} = V_{\text{LAND}} \cos \Phi$$

$$\text{set } \dot{\theta} = \dot{\theta}_1 + \frac{MST \cdot V_{\text{LAND}} \cdot \sin \Phi}{IFTG + IPLG}$$

$\dot{\theta}_1$ = rotational velocity of leg at time of landing
 $x, y, \theta, \phi, \dot{x}, \dot{y}$, and $\dot{\phi}$ will be unchanged at landing.

Phase 3. On the ground

Applied torque, τ , about the pivot is assumed to be 0 during this segment. The dynamics of the pogo stick in the ground phase of its hopping cycle are derived using Lagrange's equation: equation (1.1):

$$\frac{\partial L}{\partial q_i} - \frac{\partial}{\partial t} \left(\frac{\partial L}{\partial \dot{q}_i} \right) = Q_i$$

$$\begin{aligned}
L = T - V &= \text{Kinetic Energy} - \text{Potential Energy} \\
K.E. = T &= \underbrace{\frac{1}{2}(IFTG + (L-b)^2 MPL) \dot{\theta}^2}_{\text{rotation about foot}} + \underbrace{\frac{1}{2}IPLP \dot{\phi}^2}_{\text{rotation of body}} + \underbrace{\frac{1}{2}MST \dot{b}^2}_{\text{linear motion of leg}}
\end{aligned}$$

$$\begin{aligned}
P.E. = V &= \underbrace{MST \cdot GR \cdot (L-b) \cos \theta}_{\text{height above ground}} + \underbrace{kb^2}_{\text{compression in spring}}
\end{aligned}$$

$$L = \frac{1}{2}IFTG + \frac{1}{2}L^2 MPL \dot{\theta}^2 - Lb MPL \dot{\theta}^2 + \frac{1}{2}b^2 MPL \dot{\theta}^2 + \frac{1}{2}IPLP \dot{\phi}^2 + \frac{1}{2}MST \dot{b}^2 - MST \cdot GR \cdot (L-b) \cos \theta - \frac{1}{2}Kb^2$$

$$\frac{\partial L}{\partial \theta} = MST \cdot GR \cdot (L-b) \sin \theta$$

$$\frac{\partial L}{\partial b} = -MPL \cdot L \cdot \dot{\theta}^2 + MPL \cdot b \cdot \dot{\theta}^2 - Kb + MST \cdot GR \cdot \cos \theta$$

$$\frac{\partial L}{\partial \phi} = 0$$

$$\frac{\partial L}{\partial \dot{\theta}} = IFTG \dot{\theta} + L^2 MPL \dot{\theta} - 2Lb MPL \dot{\theta} + b^2 MPL \dot{\theta}$$

$$\frac{\partial L}{\partial \dot{b}} = MST \dot{b}$$

$$\frac{\partial L}{\partial \dot{\phi}} = IFTG \dot{\phi}$$

$$\frac{\partial}{\partial t} \left(\frac{\partial L}{\partial \dot{\theta}} \right) = IFTG \ddot{\theta} + L^2 MPL \ddot{\theta} - 2Lb MPL \ddot{\theta} - 2 \cdot L \cdot MPL \dot{b} \cdot \dot{\theta} + MPL b^2 \ddot{\theta} + 2MPL b \dot{b} \dot{\theta}$$

$$\frac{\partial}{\partial t} \left(\frac{\partial L}{\partial \dot{b}} \right) = MST \ddot{b}$$

$$\frac{\partial}{\partial t} \left(\frac{\partial L}{\partial \dot{\phi}} \right) = IPLP \ddot{\phi}$$

combining into (1.1):

$$-\tau = -MST \cdot GR (L-b) \sin \theta + IFTG \ddot{\theta} + L^2 MPL \ddot{\theta} - 2Lb MPL \ddot{\theta} - 2 \cdot L \cdot MPL \dot{b} \cdot \dot{\theta} + MPL b^2 \ddot{\theta} + 2MPL b \dot{b} \dot{\theta}$$

$$0 = -MPL \cdot L \cdot \dot{\theta}^2 + MPL b \dot{\theta}^2 - Kb + MST \cdot GR \cos \theta - MST \ddot{b}$$

$$\tau = IPLP \ddot{\phi}$$

note that:

$$x = (L-b) \sin \theta + \text{const}$$

$$\dot{y} = (L-b) \cos \theta$$

yielding:

$$\begin{aligned}
\dot{x} &= (L-b) \cos \theta \dot{\theta} - \dot{b} \sin \theta \\
\dot{y} &= -(L-b) \sin \theta \dot{\theta} - b \cos \theta \\
\dot{b} = \dot{b}' &= (-MPL \cdot L \cdot \dot{\theta}^2 + MPL b \dot{\theta}^2 - Kb + MST \cdot GR \cdot \cos \theta) / MST \\
\ddot{b} &= b' \\
\ddot{\theta} = \ddot{\theta}' &= \frac{-MST \cdot GR (L-b) \sin \theta - 2MPL \cdot L \cdot \dot{b} \cdot \dot{\theta} + 2MPL b \dot{b} \dot{\theta} + \tau}{-IFTG - MPL \cdot L^2 + 2MPL \cdot L \cdot b} \\
\ddot{\phi} = \ddot{\phi}' &= \frac{\dot{\theta}}{\dot{\phi}} = \frac{\tau / IPLP}{\dot{\phi}} \\
\dot{\phi} &= \phi'
\end{aligned}$$

This system of first order differential equations may be integrated numerically until $b \nabla 0$, at which time the pogo stick leaves the ground.

Phase 4. Ground to Air

Set $\dot{b} = 0$. All other parameters remain unchanged upon takeoff. Proceed to capital phase 1, in the air.

Continued on page 53

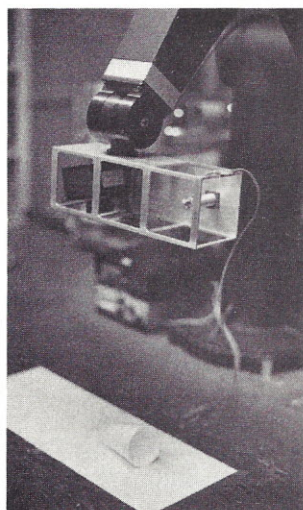
AAAI CONFERENCE

PHOTOS BY ERIC SAUND

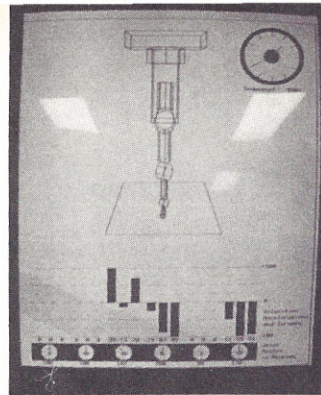
The 1982 conference of the American Association for Artificial Intelligence was held August 18th through the 20th at Carnegie-Mellon University and the University of Pittsburgh, in Pittsburgh, Pennsylvania. Almost one hundred papers were presented in 13 research areas of artificial intelligence, including robotics and computer vision. On two evenings, the Computer Science Department and the Robotics Institute of Carnegie-Mellon University held an open house to exhibit robotics research in progress. In addition, a commercial exhibit program featured booths for publishers, businesses marketing AI technology, and companies selling computer hardware and software tools.

Two robotics papers dealt with directing a mobile robot along a path strewn with obstacles. Rod Brooks of MIT proposed a relatively quick method for finding paths in not-too-constrained spaces. The algorithm explicitly represents free space as a two-dimensional form of the generalized cone. This method has previously been used to model three-dimensional objects.

L.Y. Shih, of the National Research Council of Canada, suggested an automatic path-finding method for a mobile robot, in which each obstacle is treated as if it exerted a repulsive force on the robot. Presumably, the final goal and intermediate goals are treated as attractive forces. Though the overall path might be specified by the strategic placement of intermediate goals, the detailed path is not preplanned; rather, it is determined enroute by computations based on the robot's current position relative to attractors and repellers.



Using structured light to identify and derive position and orientation of objects for industrial applications of computer vision.

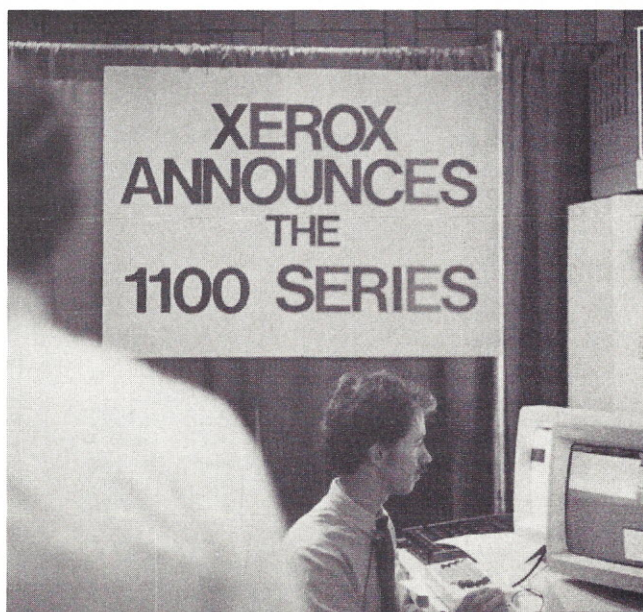


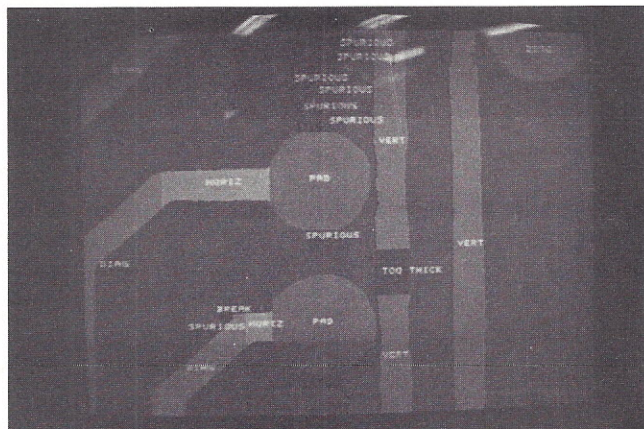
Hans Moravec of Carnegie-Mellon University described his mobile robot, which is currently under development. The robot utilizes 12 on-board processors (half of them 68000s) plus communications to a large external computer that performs image interpretation. Moravec stated, "A robot can have no excess of computing power; no matter what, you can always use more." His robot employs three independently steerable and drivable wheels, which give the robot all three degrees of freedom in a plane (translation in two directions, plus rotation). The

wheel arrangement also allows the robot to simulate, by appropriate software, any robot wheel configuration.

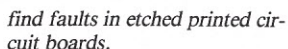
During the open house, the Computer Science Department and the Robotics Institute of Carnegie-Mellon University displayed the work of 15 research groups concerned with robotics. Topics ranged from the study of fundamental theoretical issues to the development of commercially viable applications, with emphasis on the latter.

Xerox is now selling three individual-user computers which run LISP.





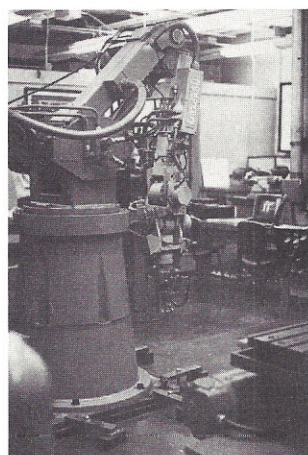
*The Visual Inspection Laboratory
uses automated visual methods to*



Symbolics introduces its newest LISP machine, the 3600.

A robot arm which uses rare-earth, direct-drive motors instead of conventional motor/gear assemblies has been built to study dynamics in the absence of excessive joint friction and gear backlash.

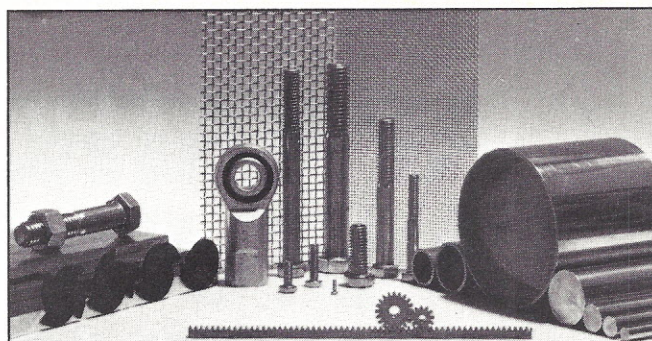
Several labs employ commercial robot arms to explore robotics assembly techniques. The Flexible Assembly Laboratory has developed special grippers for the Unimation PUMA robot to enable it to pick up small parts such as electronic components. In the Flexible Manufacturing Laboratory, a Cincinnati Milacron robot



This direct-drive arm uses rare-earth DC motors without gears. This system allows arm control research without worrying about friction and backlash.

manipulates jet turbine blades in various stages of manufacturing for inspection.

The Legged Locomotion Laboratory is studying dynamic balance in walking. A pneumatically-powered, one-legged planar hopper is able to balance under a variety of control strategies. A three-dimensional version of the one-legged walking machine will eventually carry a human operator who will have to specify only speed and direction — all leg functions will be under computer control.



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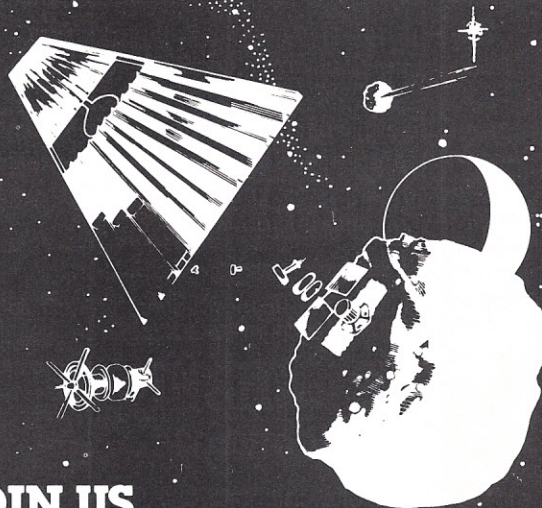
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ARMATRON: A STUDY IN ARM ENGINEERING

Mark Robillard

3 Peach Lane, Townsend, Massachusetts 01469

Anyone who has read my articles over the course of this year has probably noticed that, when it comes to supplying a starting point for robotics, I tend to support the local toy merchant. Toys, although intended for children, are designed by adults. More often than not the designer must surmount many engineering difficulties to accomplish the necessary price/performance ratio. Since this is the beginning

has capabilities usually found only in much more expensive experimental arms. You maneuver Armatron using two joysticks. These controls allow the whole arm to rotate left or right, to raise and lower, to bend at the elbow left and right, and to raise or lower the hand assembly. Turning the joystick shafts rotates the wrist and opens and closes the hand. Not bad for \$48.47 at a local discount toy store!

That price puts it at about one-tenth the cost of the closest experimental arm. This does not mean you get one-tenth the capabilities. I have lifted eight ounces straight up with the arm. Its reach is 12 inches, fully extended, yet it can fold back on itself and pick up anything close to its base. It is addictive after you first flip the power switch. If you buy one for yourself, either get another for the kids or don't let them see it.

Mechanics. Photo 2 is a view of the joystick control assembly. These shafts position gears within the unit and have no relationship to the type of control used in computer games. Photo 3 shows how the joystick interacts with the gear mechanism. The large gear in the background is actually a series of independent gears seated into each other. This is called a planetary gear system because the gears rotate like the planets. Each joint has a separate gear.

Photos 3 through 7 show each joint. Photo 6 also provides a complete view of the hand, which is equipped with rubber anti-slip grippers. All these joints are controlled by one rather small motor which is located in the base and powered by two D cell batteries.

Figure 1 depicts the gearing action used to raise and lower the shoulder. The gear ratio increases torque. At the elbow are four shafts with gears. Figure 2 illustrates the interaction and purpose of each gear. Figure 3 explains the gear mechanism of the wrist/hand assembly. The two-pincer hand design uses a unique spring-loaded coupling between its drive gears and the finger mechanisms as shown in figure 4.

Photo 1. Complete Armatron from Tomy Toys. Also included with the arm are various shapes and forms used for practice manipulations. Two D cell batteries (not included) provide the motive power.

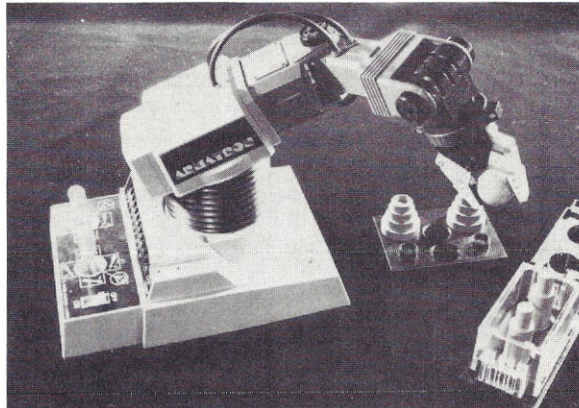
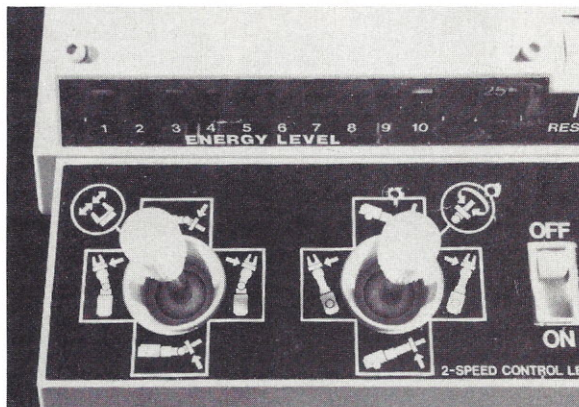


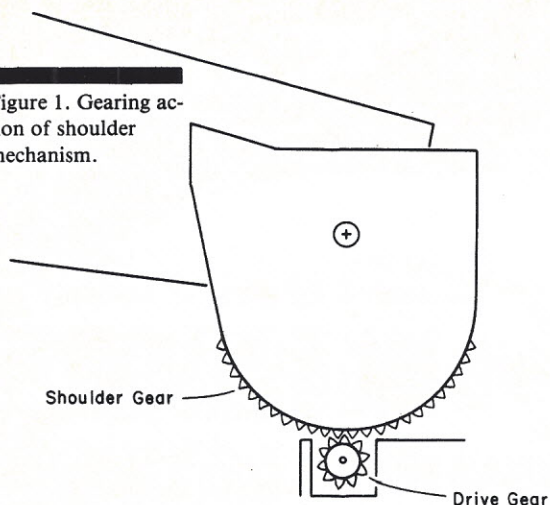
Photo 2. Armatron joystick control platform. These shafts move gears in and out of mesh within the base.



of the holiday season and toy advertisements are becoming the most popular show on TV, I find it only fitting that we investigate a new robotics toy.

The toy is called Armatron (see photo 1). Tomy Toys of California has imported a highly functional miniature robot manipulator from Japan. Armatron

Figure 1. Gearing action of shoulder mechanism.



Automatic Control. Joysticks are fun, but I soon started to think about the possibility of controlling Armatron with a computer. To avoid the complication of cutting up the device's internal mechanisms, I chose to emulate a hand controlling the joysticks rather than replacing them. This approach is not without its problems. What must be accomplished is linear motion, forward and back, left and right; don't forget the turning action to rotate the wrist and operate the hand.

There are a number of possible approaches to the problem, but some are severely limited because of the lack of space in the joystick control area. The first mechanism I built converts the rotary motion of a motor into linear motion. Figure 5 depicts the design. My design imitates the inside of a conventional resistor joystick.

The typical resistor joystick contains two mechanical guideways called bails. These bails guide the stick left or right, depending on which direction the motor is turning. The slot in the bail allows the stick to travel forward and backward as a result of the other motor's action. Two motors provide four directions. I should mention that turning off all power to the motor allows the built-in spring to return the Armatron joystick to the center, or off, position.

Photo 8 shows a wooden frame I constructed to hold the motors and the bails in place. I used heavy wire, such as the kind used to hang drop ceilings, to form the bails. The motor must produce a fair amount of torque. I used Mabuchi RE-56 slot car motors, which are available in most electronics or surplus stores. They mount from the front and are only 1 1/4 inches in diameter.

Motor Interface. Figure 6 is a schematic of a typical motor control circuit which can be used for each motor. The circuit is compatible with standard TTL levels. Refer to the article "Inexpensive Arm-Hand System" (*Robotics Age*, May/June 1982, page 20) for an explanation of motor circuit operation. This

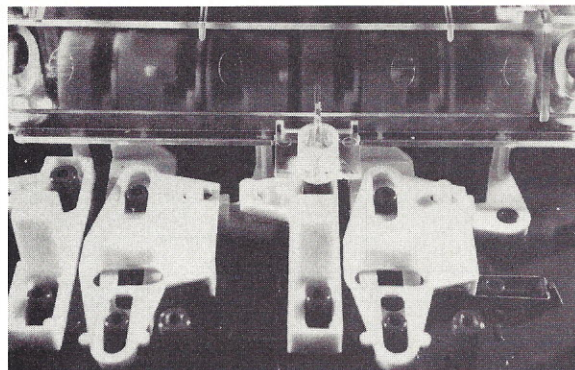


Photo 3. Joystick action of gear meshing. The large cylinder contains a multitude of gears. Moving the joystick causes a small pointer to move on the gear cylinder, allowing certain gears to mesh.

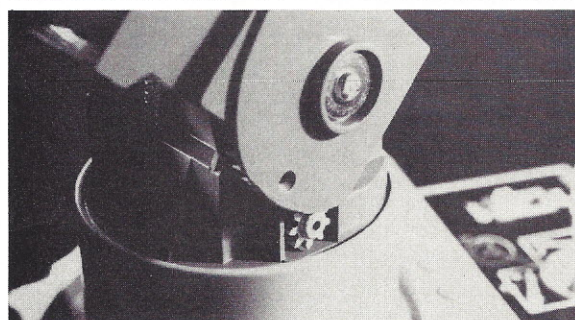


Photo 4. Close-up view of shoulder joint with decorative cover removed.

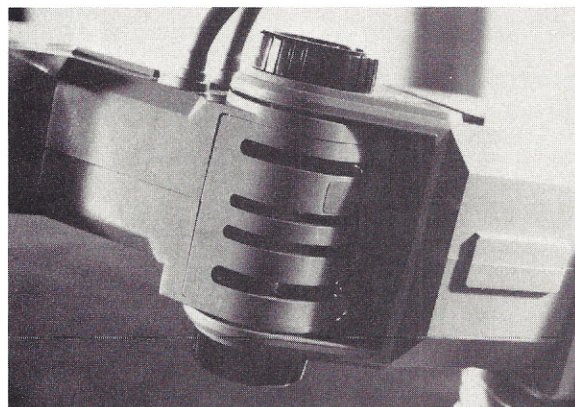


Photo 5. This view of the elbow joint shows the four gears used to provide motion from elbow to hand. Figure 7 explains each gear.

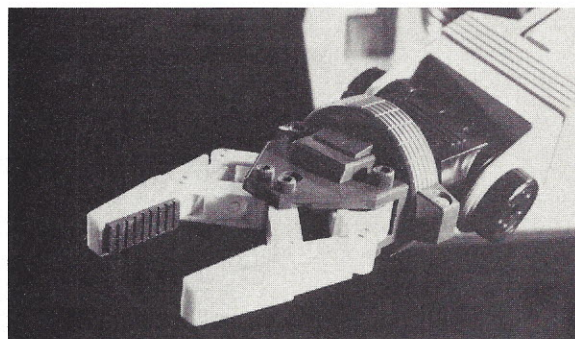


Photo 6. Close-up view of hand/wrist assembly. The hand is capable of opening up to two inches while keeping the jaws parallel at all times.

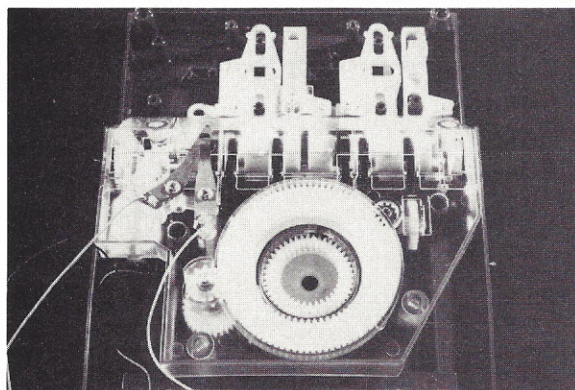


Photo 7. Inside view of the main gear box located in the base. That little motor moves everything. The planetary gear arrangement is visible in center.

Figure 2. Elbow gear action. The bottom gear moves the elbow left and right. The top gear transfers the wrist raise and lower power. The next to the bottom gear rotates the wrist. The remaining gear transfers open and close power to the hand.

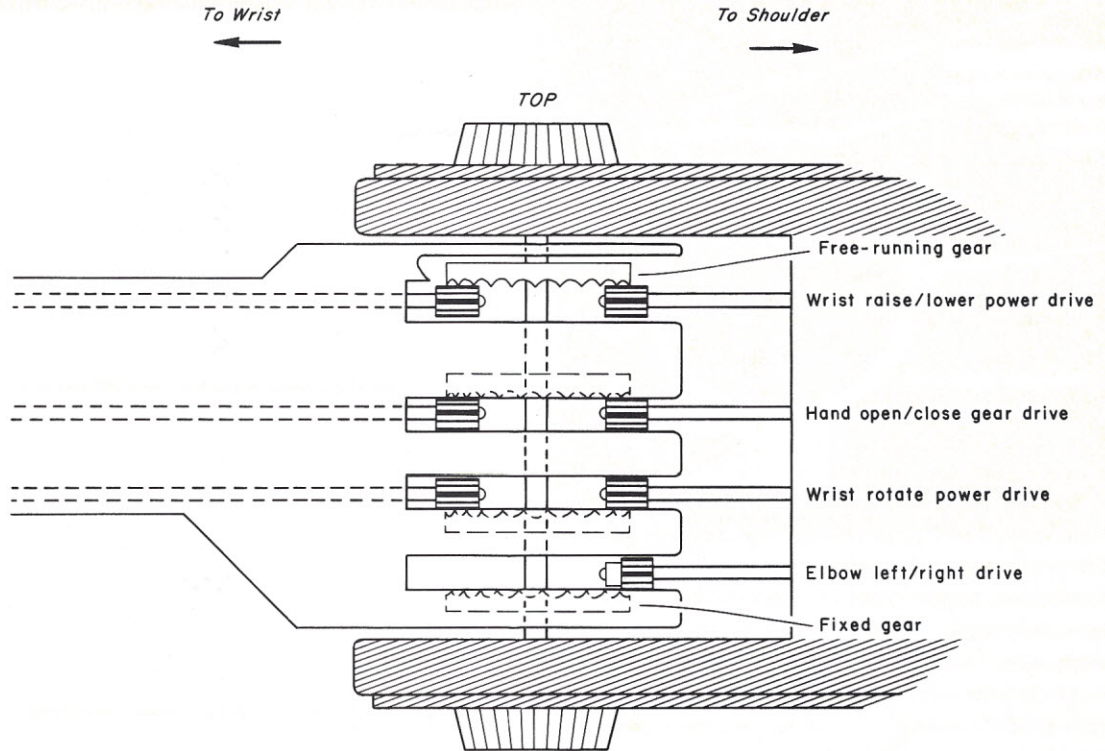
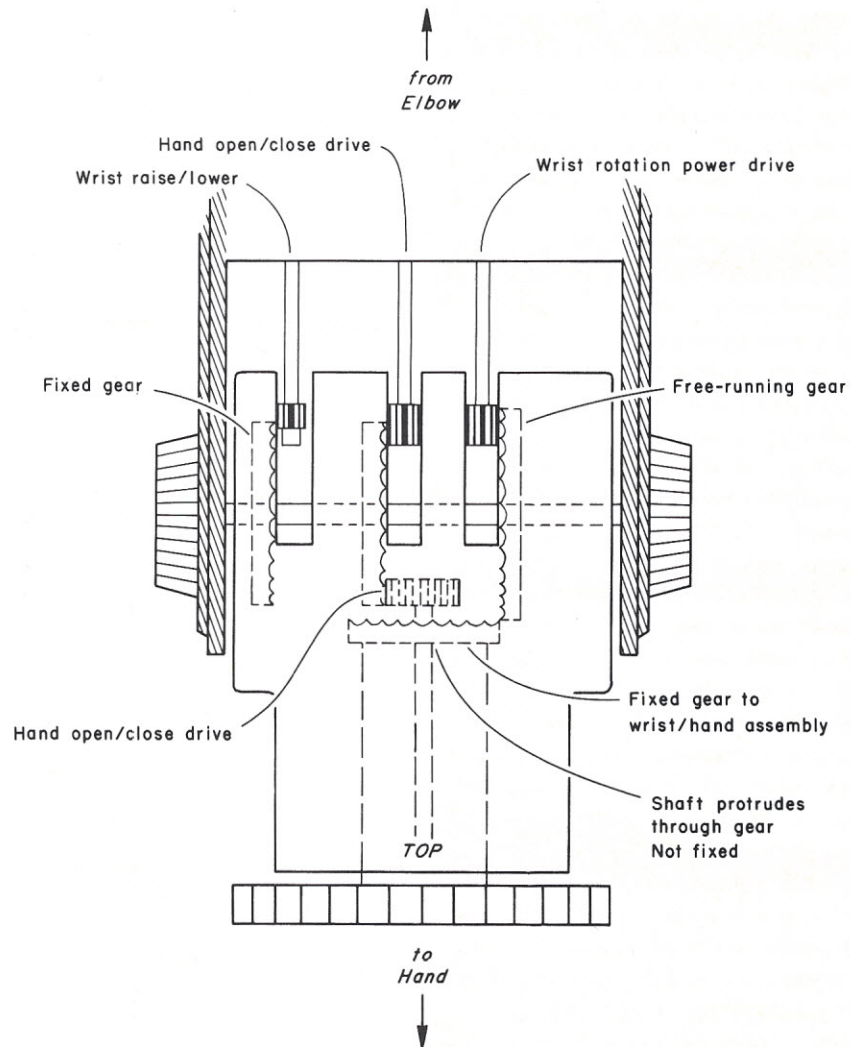


Figure 3. Wrist/hand mechanical action. The center gear opens and closes the hand. The left gear raises and lowers the wrist. The remaining gear rotates the wrist.



circuit is somewhat different, however, since I have used a specific motor control IC (TPQ6002). This IC has both NPN and PNP transistors in it so that only one package is required per motor. It is very inexpensive and is readily available.

Solenoid Control. Another control possibility is to use solenoids. These devices perform linear motion but can only provide one direction of movement. It is necessary, therefore, to use eight solenoids. Because of space limitations on the joystick housing, they must be mounted on a separate platform.

Figure 7 depicts a typical way of mounting the solenoids. An elastic control cable is connected to each of the solenoid plungers, then to the joystick shaft. A means of stopping the shafts from pulling out when they are not energized is also needed.

Solenoid control is by far the more exact method, but it requires more mechanical pieces. The interface to the solenoids is extremely simple, as shown in figure 8. Using high-current peripheral driver ICs simplifies the process quite a bit.

Rotary motion for hand and wrist movements is the toughest part of the emulation. Although the joysticks turn only a few degrees in either direction, they do require quite a strong force to move. I suggest you cement a gear on the top of each stick, then attach a motor with a smaller gear so that it meshes with the first. This increases the torque. Mount the motor so that it travels with the stick.

After all this mechanical effort, you will see that the only disadvantage of Armatron from an external control standpoint is that it is all mechanical inside. I wish that it was programmable like the Milton Bradley Big-Trak.

Computer Control. The computer can control whichever mechanical interface you choose. A parallel port can connect the motor or solenoid drivers and the computer. Each code controls one direction device. All you need is a teach-and-learn program.

I have chosen the following keys to control Armatron:

Key	Function
1	Raise entire arm
2	Lower entire arm
3	Turn entire arm right
4	Turn entire arm left
5	Turn elbow right
6	Turn elbow left
7	Raise wrist
8	Lower wrist
9	Rotate wrist right
0	Rotate wrist left
O	Open hand
C	Close hand

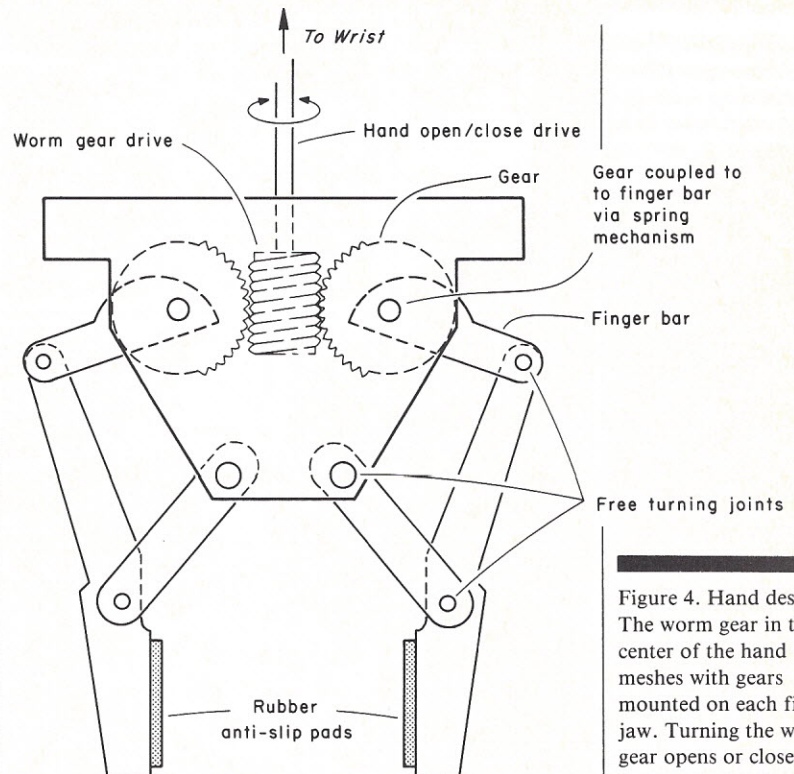


Figure 4. Hand design. The worm gear in the center of the hand meshes with gears mounted on each finger jaw. Turning the worm gear opens or closes the fingers via a spring coupling.

There are four command keys associated with the program:

Key	Command
M	Set manual mode — no memory
A	Set automatic mode — memorize each keypress
B	Begin recall from memory
S	Stop recall from memory

Note: The program listing shown on page 45 is a more advanced version that will prompt the user for commands.

After stopping Armatron in the middle of a memory recall sequence, push B again to reset and start the sequence from the beginning. Be sure, before you start a memory recall sequence, that Ar-

Text continued on page 46.

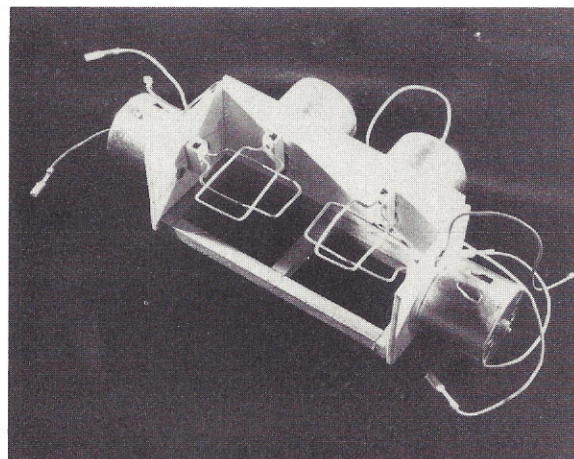


Photo 8. Using motors to produce linear action. This assembly is made up of four RE-56 motors with attached wire bails.

Figure 5. Details of bail construction and motor placement. Motorized bails provide linear motion.

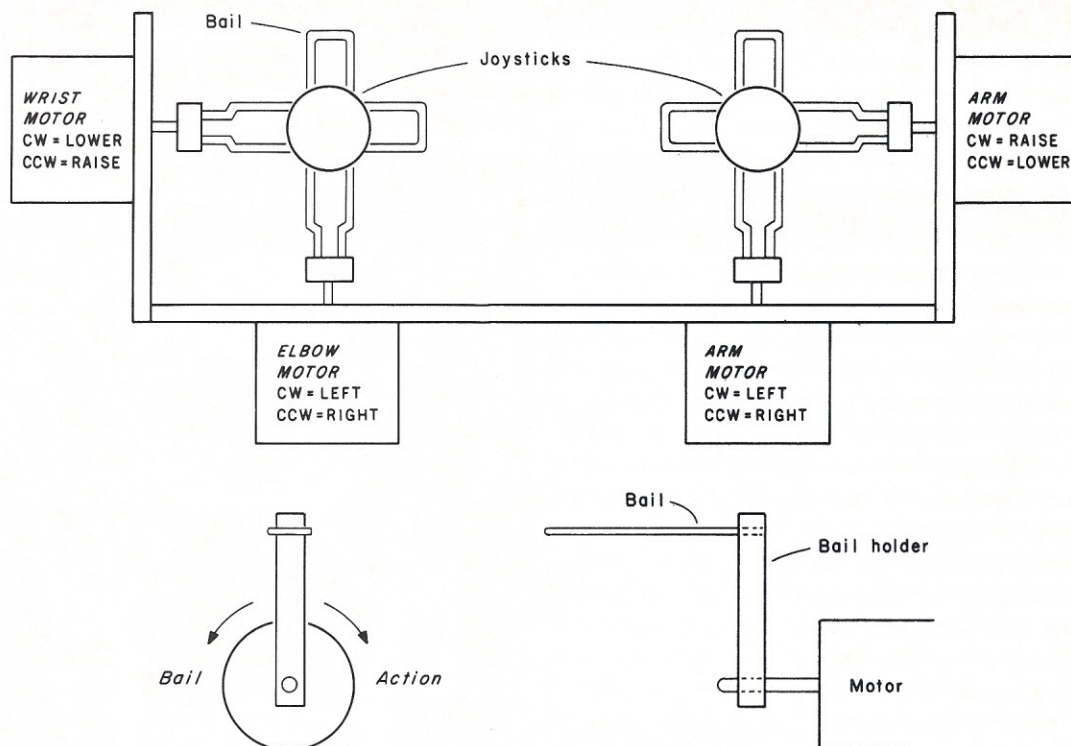
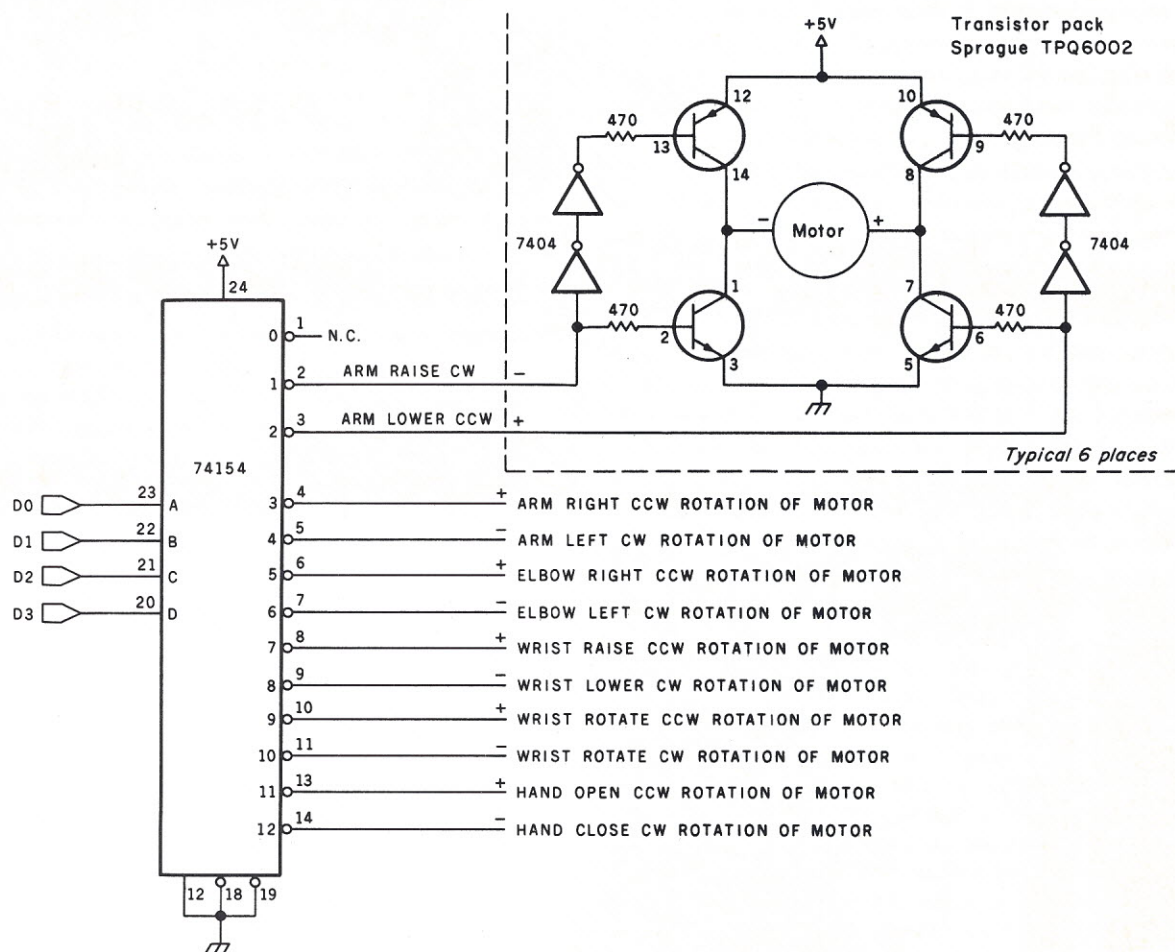


Figure 6. Schematic of motor driver system. Commands in the form of a four-bit number energize one direction at a time.



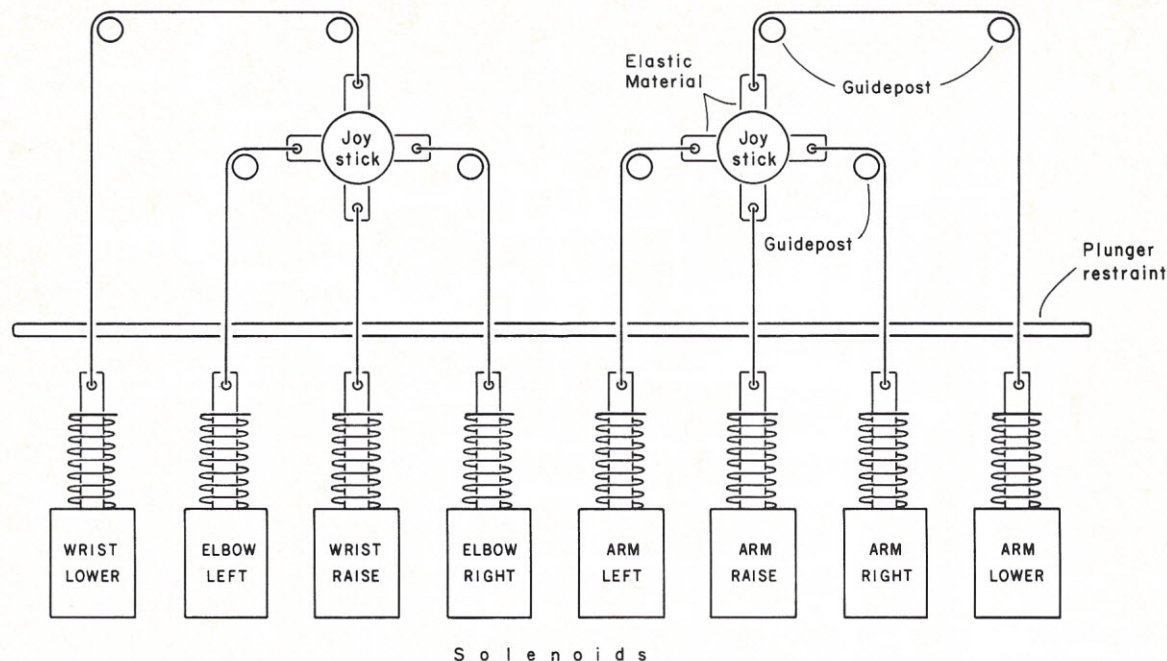


Figure 7. Solenoids can be used to provide linear motion. Energizing a solenoid moves the joystick in the desired direction. Turning off power to the solenoid allows the joystick to return to its center position.

```

1 '
2 '   **ARMATRON COMMANDER**
3 '
4 '
5 '   INITIALIZE
6 '
7 '
8 CLEAR 2000
9 ARMOUT=49152
10 DIM CODES$(25): DIM DURATION(25):POKE ARMOUT,0
20 PLACE=1:TIME=0:CLS:KEYVALUE=0
30 PRINT"SELECT THE FOLLOWING"
40 PRINT"1) MANUAL MODE"
50 PRINT"2) AUTOMATIC MODE"
60 A$=INKEY$:IF A$="" THEN GOTO 60
70 IF A$="1" THEN GOTO 100
80 IF A$="2" THEN GOTO 150
90 CLS: GOTO 30
95 '
96 '   MANUAL MODE
97 '
98 '
100 CLS:PRINT"MANUAL INPUT MODE"
110 A$=INKEY$:IF A$="" THEN GOTO 110
120 IF A$="S" THEN POKE ARMOUT,0:PRINT"STOPPED": GOTO 20
130 GOSUB 430 'CONVERT AND SEND
140 GOTO 110
145 '
146 '   AUTOMATIC MODE
147 '
148 '
150 CLS:PRINT"AUTOMATIC MODE"
160 PRINT"SELECT THE FOLLOWING"
170 PRINT"1) TRAIN"
180 PRINT"2) RECALL FROM MEMORY"
190 PRINT"3) RETURN TO MANUAL"
200 A$=INKEY$:IF A$="" THEN GOTO 200
210 IF A$="1" THEN GOTO 249 '   STORE SUBPROGRAM
220 IF A$="2" THEN GOTO 339 '   RECALL SUBPROGRAM
230 IF A$="3" THEN GOTO 100 '   MANUAL MODE
240 GOTO 150
245 '

```

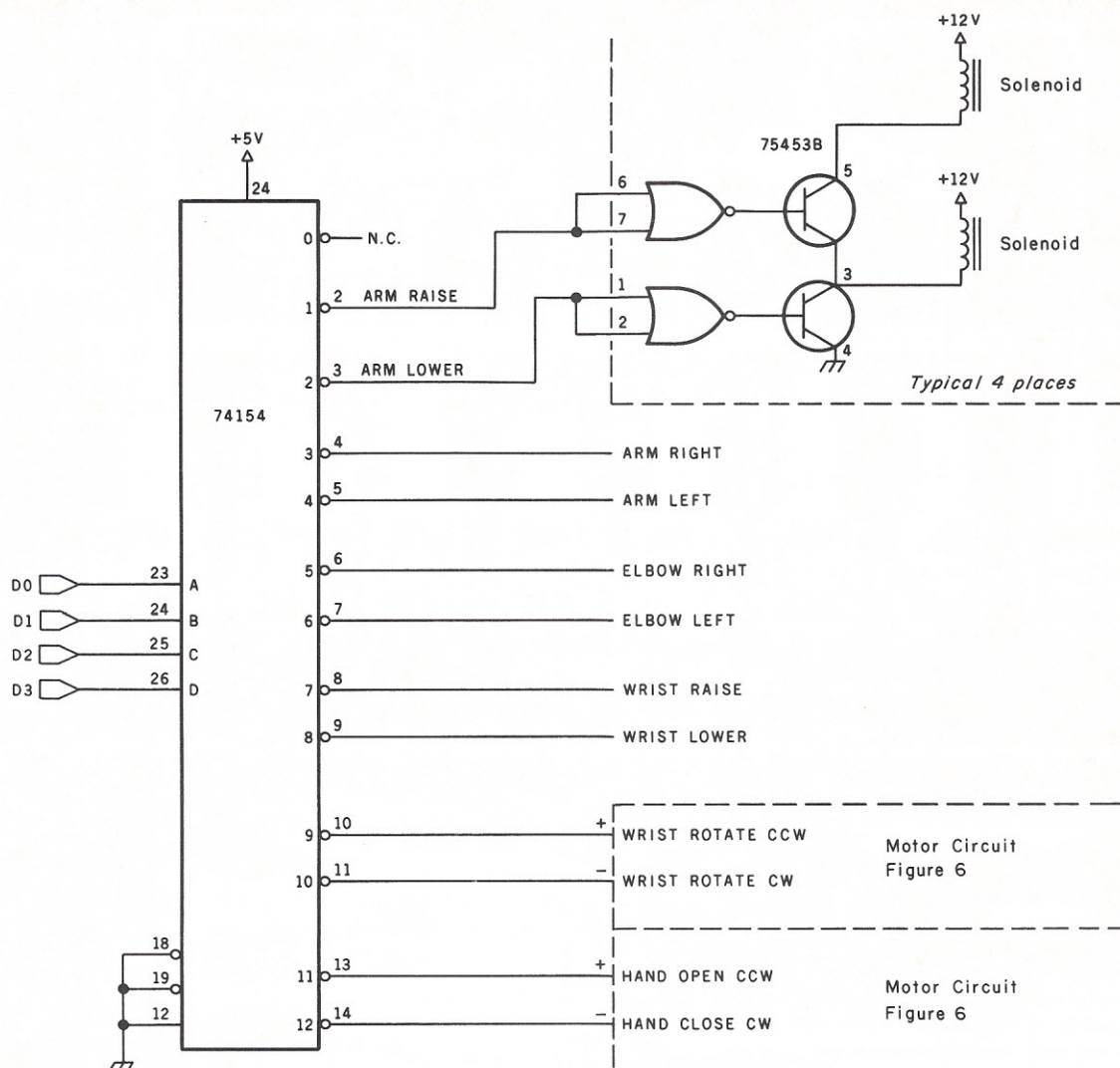
```

246 '   STORE SUBPROGRAM
247 '
249 CLS:PRINT"TRAINING"
250 A$=INKEY$:IF A$="" THEN GOTO 250
260 GOSUB 430 '   CONVERT AND SEND
270 CODES$(PLACE)=A$
280 A$=INKEY$
290 IF A$="" THEN TIME=TIME + 1:GOTO 280
300 DURATION(PLACE)=TIME
310 PLACE=PLACE + 1
320 IF PLACE < 25 THEN GOTO 330
322 PRINT"MEMORY FULL"
325 FOR T=1 TO 250:NEXT T
328 GOTO 20
330 TIME=0:GOTO 260
335 '
336 '   RECALL SUBPROGRAM
337 '
339 CLS:PRINT"RECALL FROM MEMORY"
340 A$=CODES$(PLACE)
350 GOSUB 430 '   CONVERT AND SEND
360 TIME=DURATION(PLACE)
370 IF TIME <> 0 THEN TIME = TIME - 1:GOTO 370
375 FOR T=1 TO 70:NEXT T
380 PLACE=PLACE + 1
390 IF PLACE < 25 THEN GOTO 400
392 PRINT"END OF PROGRAM"
395 FOR T=1 TO 200:NEXT T
398 POKE ARMOUT,0:GOTO 20
400 A$=INKEY$
410 IF A$<>" " THEN POKE ARMOUT,0:PRINT"STOPPED":GOTO 20
420 GOTO 340
425 '
426 '   CONVERT AND SEND SUB PROGRAM
427 '
428 '
430 IF A$="0" THEN KEYVALUE = 10:GOTO 470
440 IF A$="O" THEN KEYVALUE = 11:GOTO 470
450 IF A$="C" THEN KEYVALUE = 12:GOTO 470
460 KEYVALUE = VAL(A$)
470 POKE ARMOUT,KEYVALUE:PRINT KEYVALUE
480 RETURN

```

Listing 1. BASIC listing of AMATRON program-mable control program written in Microsoft BASIC. ARMOUT is set to a known control location.

Figure 8. Schematic of solenoid interface using same four-bit number system as the motorized circuit.



matron is positioned where you want it to begin. The control program accepts up to 25 different commands in a sequence. You can change this number to suit different memory requirements.

The Program. The Armatron control program (listing 1) begins with an initialization routine. This part of the program sets all variables and memory locations to known values. The system is initialized in manual mode. Any movement key simply activates the appropriate solenoid or motor. Movements are not remembered until the automatic (A) key is pressed. Enter the key scanning portion next. Here the use of the Microsoft BASIC command INKEY is critical. If your version of BASIC does not have this command, you can substitute INPUT A\$, but every command key you hit must be followed by a carriage return or ENTER.

Once a key is detected, the command interpreter takes over. It systematically compares what it received with the list of available command buttons.

When in automatic, a string array that contains each entered movement command is formed. First,

the key letter, then the duration of activation is stored. When a different key is struck, a new array location is opened. Pauses between commands are not stored.

The B command tells the program to start at the top of the array and begin pulling values of key codes and their lengths, then send them to the operation handler for execution. This is not as simple as it sounds. Study the listing for specific program action and modify to customize it.

This program allows almost the degree of programmability of the motion platform I described in "Constructing An Intelligent Mobile Platform" (*Robotics Age*, July/August 1982, page 41) but it still does not allow total local control. Consider taking the simple Z8 computer system and adapting it for use here. Almost the same parallel interface could exist; only the program would change. How about fitting the motion platform with Armatron, then adding voice command control from last issue? Start working on it. Drop me a line with your results, and in a future article, I will disclose my efforts at fitting it all together. □

INVENTION DOCUMENTATION: A Primer

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2001 Jefferson Davis Highway
Arlington, Virginia 22202

It is essential to maintain detailed records during the development of any robotics or other engineering project, whether you are a private inventor or employed by a company. Through proper documentation, you can track your own progress and determine the best course for future work. Thorough and accurate documentation is also a must for writing reports and developing papers for publication.

There is another reason to document your work; unless you keep good records, you may not receive proper credit for your inventions, either within your company through reports, or on the outside through patents.

A patent is basically a contract between an inventor and the government which gives the inventor the right to exclude others from making, using, or selling his or her invention in this country for a period of 17 years. This right can be licensed or sold. The inventor must make a full disclosure of the invention in the patent application. The U.S. patent application is maintained in secret. Once the Patent Office issues a patent, the invention becomes public-

ly known. After 17 years, the invention becomes dedicated to the public. A U.S. patent is effective only in the United States; to obtain foreign patent protection, you must apply in those countries for which protection is required.

Until recently, it was uncertain whether computer programs or inventions involving programmed computers could receive patent protection. In accordance with recent Supreme Court cases, however, it is now clear that many forms of programmed systems can be patented. One Supreme Court case involved a form of robotics wherein molding of rubber within a mold press was controlled so that the rubber was molded perfectly every time. Temperature within the press was continuously measured, calculations were made in accordance with a known equation, and the press was opened at exactly the right time to form a nearly perfect product.

Particular forms of documentation are needed to establish and protect patent rights for your invention. Proper documentation proves that you are correctly named as an inventor and indicates whether others should be named as co-inventors. If the application for a patent is prepared by a patent attorney, he or she will probably want to see the documentation and receive as much disclosure as possible in order to draft a thorough and accurate patent application. The patent may initially be refused on the basis that the invention was earlier completed by another inven-

tor. Your carefully developed records can help to prove that you are the first inventor and therefore the one entitled to the patent.

If the patent is enforced against a competitor in court, you may have to prove an early completion date of your invention to avoid having your patent held invalid because the work was completed earlier in this country. On the opposite side, you may want to provide documentation to show that a patent being enforced against you is invalid because you completed the invention prior to the other inventor.

What is Patentable. Before you learn the type of documentation required to help protect your invention, you need to know a bit more about patents.

To be patentable, an invention must be new, useful, and unobvious. When a patent application is filed with the U.S. Patent and Trademark Office, the Examiner to which the application is assigned checks the records to determine whether the invention is new and, if so, whether it is unobvious. During negotiation between the Examiner and the applicant (generally through his or her attorney), the Examiner brings forward any evidence in the form of prior patents or publications which shows that the invention is not patentable over the prior art. "Prior art" is defined as the state of the technology at the time the application is filed. The applicant may argue that the invention is different from the prior art, or he or she may have to prove completion of the inven-

STEPHEN A. BECKER, who has a Master of Science degree in Electrical Engineering, has been granted two patents for his work in electronic control systems while working as a research engineer. After obtaining a law degree in 1975, he entered the field of patent, trademark, and copyright law. Mr. Becker now specializes in protection of intellectual property with particular emphasis in computers and is a partner in the patent law firm of Lowe, King, Price & Becker, 2001 Jefferson Davis Highway, Suite 209, Arlington, Virginia 22202.

tion in this country before the invention shown in the patents or publications. The applicant must do this using proper written documentation, not by making allegations.

The Examiner may advise that another applicant has filed a patent application on the same invention. A so-called "interference procedure" may be declared, and each applicant given an opportunity to bring forth documented evidence showing an earlier invention date.

Keeping Records. Two elements of the completed invention, which you may have to prove by documentation, are conception and reduction to practice.

Conception is considered to occur when the invention is completely developed in the mind of the inventor. This requires more than the mere recognition of a desirable result, or of a problem or a general approach to solving the problem. Conception requires the formulation of the physical structure or process to accomplish a result or to solve a problem. You must show conception to someone who understands your idea. The best type of evidence to prove conception is probably a written description of the idea in a notebook, including any necessary drawings. The notebook should be read, dated, and signed by someone who understands the inventive concept but is not a co-inventor or may become named as a co-inventor.

The one form of reduction to practice requires actually building and testing the invention. (Editor's Note: Construction of the invention is not a requirement for filing a patent application.) Computer simulation of a system alone is probably not adequate evidence for reduction to practice.

The reduction to practice must be witnessed by someone else. An excellent witness may be an engineer or technician in your company but again, not a co-inventor or anyone who might possibly become named as a co-inventor. The witness must swear that he or she either watched the inventor carry out all the important aspects of the invention on the behalf of or at the request of the inventor. The invention must be tested to show that it does what

it is supposed to do. If you make a demonstration of the invention without a witness, you must repeat the demonstration in view of the witness. The witness for a conception can be the same witness as for a reduction to practice.

A good way to keep a permanent record of your invention is to use a numbered, bound laboratory notebook. An excellent notebook of this type is Form W-300-75, available from the Laboratory Notebook Company, 242 Suffolk Street, Holyoke, Massachusetts 01040. The notebook entries should be a running, consecutive, dated account of work conducted on your projects, as well as work of others that you have witnessed. Use a single page for each subject and each day's work. You should include in the documentation plans, test sheets, material orders, time records, and anything else that can supplement the notebook record.

Document each project on a periodic basis to show what was done, why the work was done, and by whom the work was done. The record should indicate when the work was done and what the results and conclusions were. The notebook entries should be thorough; to prove conception, the disclosure must be detailed enough to enable another person of ordinary skill in the art to understand what was in the inventor's mind. Proving reduction to practice requires enough detail to show exactly what was done to demonstrate the invention. The disclosure and reduction to practice, however, do not have to be of a commercial device.

Do not deliberately obscure your records to prevent discovery by others. This might reduce your chances of proving complete conception or reduction to practice before a court at a later date. Even worse, several years down the road, you may not be able to reconstruct exactly what you had in mind.

Try to make notebook entries on a daily basis. Make all entries into your notebook first so that the entries will be the original documentation. Any unusual delay in time between entries might show a lack of diligence which can hurt your case or might even sug-

gest that you are withholding critical documentation.

Never falsify the records. Use actual facts and dates and do not erase or tear out pages. If you make a mistake, draw a line through the incorrect words or portions of the page so that the content of the mistake remains readable. Never alter the record at a later date and do not leave large spaces on the pages. Draw a diagonal line through any significant blank spaces to prevent the inference that you filled in pages after the date.

It is helpful to show the type of reasoning and experience that led to the invention. If you attended conferences or read articles to stimulate a particular approach, indicate that in your record. If you made mistakes or changed your approach, be sure the record indicates that, since it will support the integrity of your documentation. Do not be afraid to admit an error on the record; your mistakes are just as important as your successes. Use ink or indelible pencil for making the record to reduce suspicion that you may have altered the record.

Always follow through as quickly as possible from conception to reduction to practice. Be especially careful to keep detailed records concerning the last step which results in the invention. If you fail to follow through to reduction to practice or to file a patent application in the Patent and Trademark Office in a diligent manner, you will not be able to prevail in an inventorship contest against another who followed through to a provable reduction to practice, even though the other person made his or her invention after you conceived your invention.

Finally, review your records from time to time and do not be reluctant to make the review with your co-workers. Frequently, you may have developed a number of small improvements which themselves are not patentable, but when joined with improvements by others, can result in an outstanding invention. If you work with a patent attorney, review your records with him or her from time to time to help educate the attorney in your technology and to enable the attorney to identify all patentable inventions as they evolve. □

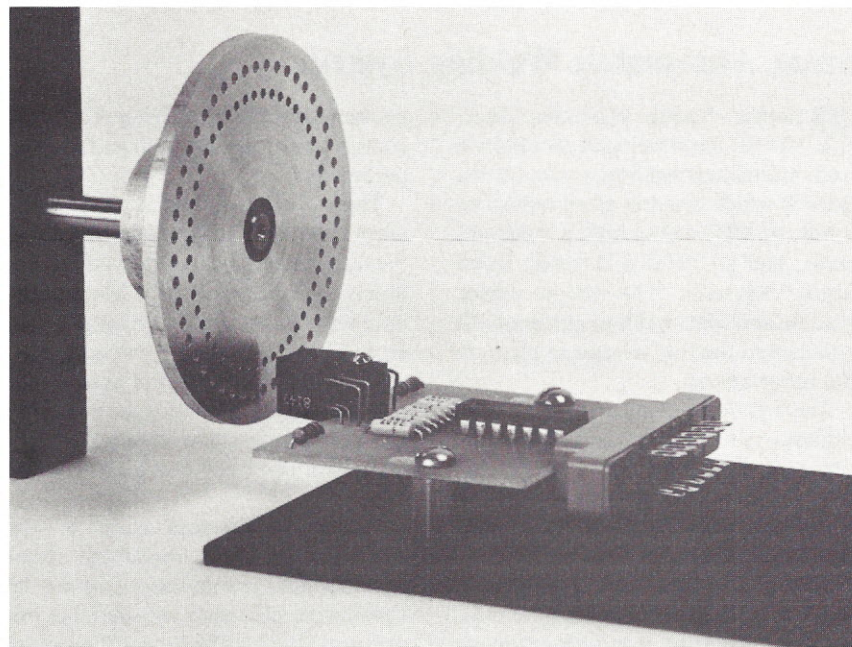
New Products

Low-cost Optical Encoders

A Priori announces a low-cost line of precision optical encoders in modular form for a host of robotics applications. They offer 50 count/turn resolution and are ideal for use in nonhostile environments.

The encoder fits onto a shaft with a unique cone-mount collar that provides concentric and wobble-free running. Standard shaft sizes are 0.125 inches, 0.250 inches, 0.375 inches and 0.500 inches. Metric sizes are available. This dual-track encoder is manufactured on a computer-controlled mill and has precise hole-to-hole registration and spacing.

Reflective IR pickup optics output a TTL dual channel, phase quadrature signal for direction sensing. A signal-processing board which connects to the pickup optics and gives as output a CW/CCW direction and rate signal is also available. This board uses error-correction circuitry which provides an accurate direction and rate signal. It does not hang up on hole transitions and generate false counts as most phase



detection schemes do. It is offered with one-, two-, or four-times resolution multiplication options. This gives an ultimate resolution of 200 counts/turn if the four-times option is chosen.

Some application areas that are in use are robot arm, wrist, and shoulder con-

trols. Angle sensing is another use. Motion control and motor speed control application areas abound. A Priori also has an adhesive strip of linear encoder tape that can take the place of the disc encoder in areas of linear encoding. This tape has etched on it a phase quadrature, dual-track pattern and operates by reflecting the incident IR. The advantage in using this linear tape is that it eliminates backlash in systems that use a gear train to generate the linear conversion using a disc encoder. Prices are as follows:

Disc-XXX (standard encoder disk. XXX represents shaft size in thousandths of an inch) — \$19.95.

PU-1 (pickup optics board) — \$19.95.

OSPB-1X, 2X, or 4X (signal-processing board. Two-channel phase quadrature signal in, direction and rate signal out. With connector) — \$24.95.

For a complete brochure listing prices and available electronics and mounting hardware, contact: A Priori, 21318 125th S.E., Kent, Washington 98031. Phone: (206) 630-2144.

CIRCLE 32

Video Analyzer

The IVS 200 is a real-time digital image processing system compatible with most video cameras and VCRs. Its features include real-time digitization and image storage with 512 by 512 by 8 bit basic resolution, real-time integration of up to 16 bits with the selection of the IVS 200 arithmetic logic unit (ALU) board, pan and scroll, reference image or mask comparison, and programmable input and output lookup tables. The system contains a high-speed interface to a desktop computer (included) and can be supplied with a variety of peripherals. Off-line processing can be performed using both IVS preprogrammed functions and user-programmed operations. Commands can be input in either BASIC or assembly code. Output channels for con-

trol of external devices are also available. For further information contact: Interactive Video Systems, Inc., 34 South Road, Bedford, Massachusetts 01730. Phone: (617) 275-5569.

CIRCLE 31



New Products

Seam Automated Welding System

Robotic Vision Systems, Inc., (RVSI) has developed an adaptive seam automated welding system (called SAWS) which consists of an industrial robot, an MIG welder unit, a minicomputer, and an RVSI 3-D vision Robo Sensor™ System. The vision sensor module and MIG welding gun are both attached to the tool mounting plate on the robot's wrist.

The 3-D Robo Sensor vision system employs proprietary state-of-the-art electro-optical and data processing techniques to accurately determine the three-dimensional spatial coordinates of the viewed seam.

SAWS provides the capability to adapt to differences in the spatial positions and widths of certain seams on car bodies coming down an assembly line

by automatically modifying the robot-controlled arc welding path and welding parameters.

There are two modes of operation: a teach mode and an operating mode. In the teach mode, the first car body on the line is used to teach the robot a reference seam vision path, a reference seam cross-section, and a reference seam welding path. During the subsequent automatic operating mode, a vision pass and a welding pass are repeated for each successive car body coming down the line.

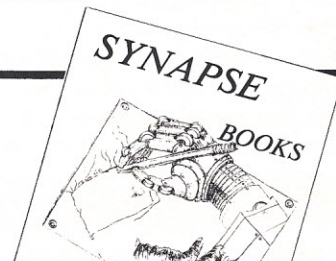
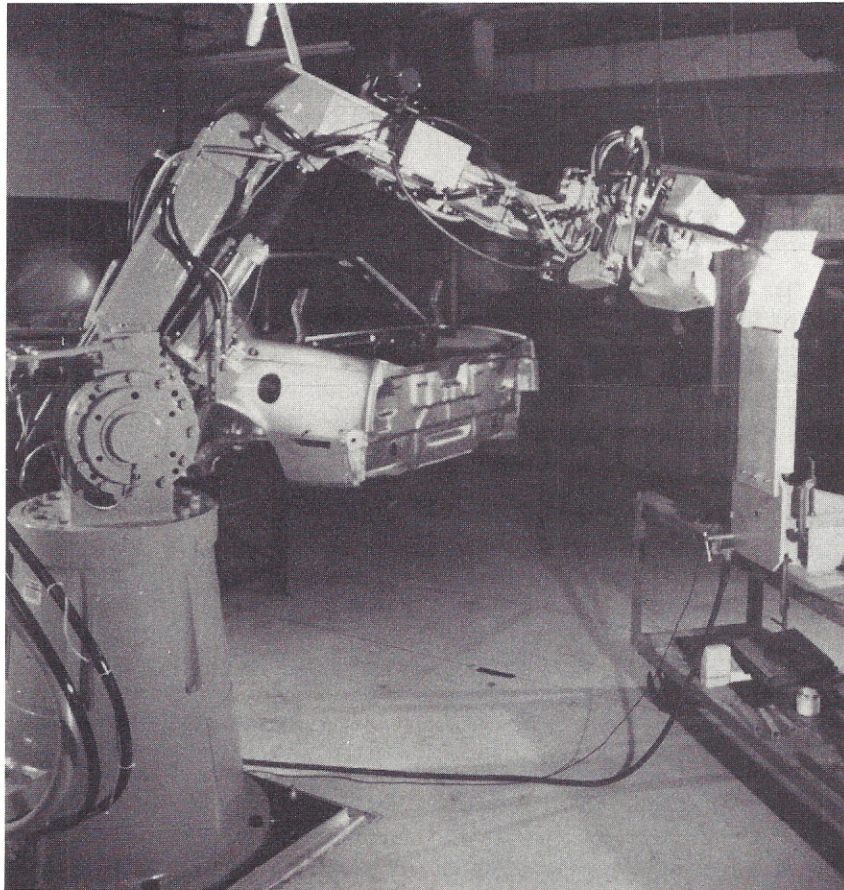
In the vision pass cycle of the automatic operating mode, the robot arm mounted vision sensor follows the vision path and senses the spatial deviation and width difference of the actual seam from the reference seam. Welding

is then performed in the welding pass, using the deviation information to correct the robot welding path to compensate for spatial differences and to adaptively adjust the welding parameters to compensate for differences in seam cross-section.

To the best of Robotic Vision Systems, Inc.'s knowledge, its adaptive seam automated welding system is the first operational system of its kind using a three-dimensional vision and data processing system in conjunction with a robot and an arc welder in an automotive assembly plant.

For further information, contact: Robotic Vision Systems, Inc., 536 Broadhollow Road, Melville, New York 11747. Phone: (516) 694-8910.

CIRCLE 33



Synapse Book Catalog

Synapse Information Resources announces its 1982 Book Catalog. This 74-page work is the most up-to-date single resource on the subjects of: automation, robotics, artificial intelligence, CAD/CAM, computer technology, cybernetics, biomedical engineering, and instrumentation.

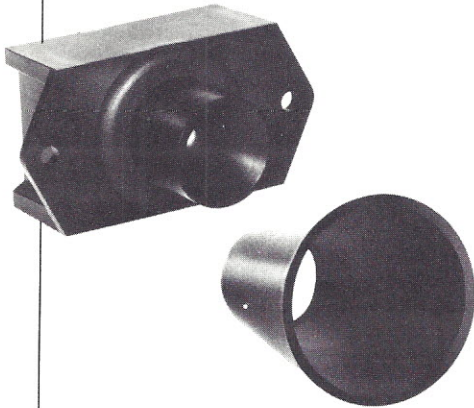
Selected titles represent the best of varying theoretical viewpoints at different technical levels, giving the user powerful assistance in meeting professional source materials requirements. In addition, some layman-oriented works have been included for those seeking knowledge outside their own disciplines. For this free catalog, contact: Synapse Information Resources, 912 Cherry Lane, Vestal, New York 13850. Phone: (607) 748-7885. CIRCLE 34

New Products

New Ultrasonic Ranging Module

Massa Products Corporation announces its Model E-200 Ultrasonic Ranging Module. The E-200 combines an air ultrasonic transducer and all interface and processing electronic circuitry necessary for detection and range measurement into one small, compact module.

The E-200 uses a 26 KHz air transducer and transmitting and receiving electronics to provide a digital pulse output. The output pulse width is directly proportional to the unit's distance from a target at a rate of 1.77 msec. per foot. The E-200 is capable of detecting objects or accurately measuring distance, from approximately two feet to over 30 feet in air, with a resolution of better than plus or minus one-half inch.

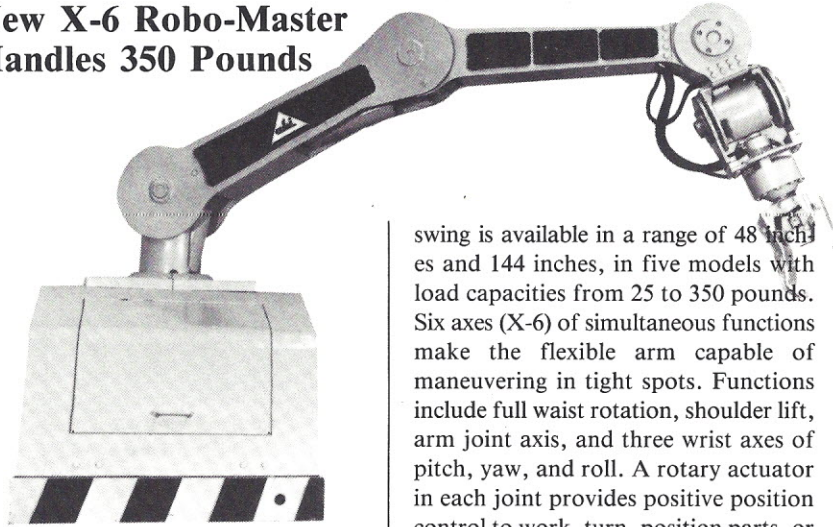


The module is ideally suited for many industrial control applications, including distance measurement, proximity detection, security sensing, counting, and robotics. Features include small size, self-contained packaging, single DC supply operation (+5 to -15 VDC) low current drain, and internal or external trigger. The price is \$150, and availability is stock to two weeks.

For further information, contact: Ronald A. Massa, Director of Marketing, Massa Products Corporation, 280 Lincoln Street, Hingham, Massachusetts 02043. Phone: (617) 749-4800.

CIRCLE 35

New X-6 Robo-Master Handles 350 Pounds



Air Technical Industries' Robo-Master can be equipped with many different styles of grippers, hands, attachments, and tools for a wide range of job applications. Six or more production processes can be located around this robot which has a waist rotation of 270 degrees. A maximum diameter

swing is available in a range of 48 inches and 144 inches, in five models with load capacities from 25 to 350 pounds. Six axes (X-6) of simultaneous functions make the flexible arm capable of maneuvering in tight spots. Functions include full waist rotation, shoulder lift, arm joint axis, and three wrist axes of pitch, yaw, and roll. A rotary actuator in each joint provides positive position control to work, turn, position parts, or execute other material handling and assembly functions. Robo-Master can handle intensive and tedious tasks in any environment that requires delicate gripping and precise touch. For more information, contact: Air Technical Industries, 7501 Clover Avenue, Mentor, Ohio 44060. Phone: (216) 951-5191.

CIRCLE 36

Pixelcaster Intelligent Visual Preprocessor

Vision Peripherals announces an Intelligent Visual Preprocessor, the Pixelcaster. The two-, three-, or four-card, S-100-sized board set allows development and implementation of image processing algorithms using any computer host. Virtually all of the information in a video signal, including color, is made accessible to any system communicating via RS-232C. Applications include video text recognition, noncontact measurement, robot vision, remote monitoring, and intrusion detection.

The Pixelcaster interfaces via RS-232C and accepts ASCII commands. It features a Z80A CPU and a high-speed memory for storing up to 1024 image samples and coordinates of the sample locations. Sample timing is referenced to the NTSC 3.579545 MHz color subcarrier, which makes for very stable sampling of TV images. Each of the

1024, four-bit pixels can come from anywhere in the TV signal, including the sync intervals or consecutive fields. The order of the pixels transmitted to the host in ASCII is independent of the order in which the samples are acquired during the TV raster scan. Special X and Y offset registers allow the specified pattern of pixels to be quickly translated about on the image, and real-time interrupts to the Z80A CPU enable processing to be synchronized to events in the video signal.

A complete Pixelcaster system, in a compact desktop enclosure with all controls and indicators on an attractive front panel, will be introduced in the fourth quarter of 1982. For more information, contact: Vision Peripherals, 2612 West Lincoln Avenue, Suite 301, Anaheim, California 92801. Phone: (714) 952-1176.

CIRCLE 37

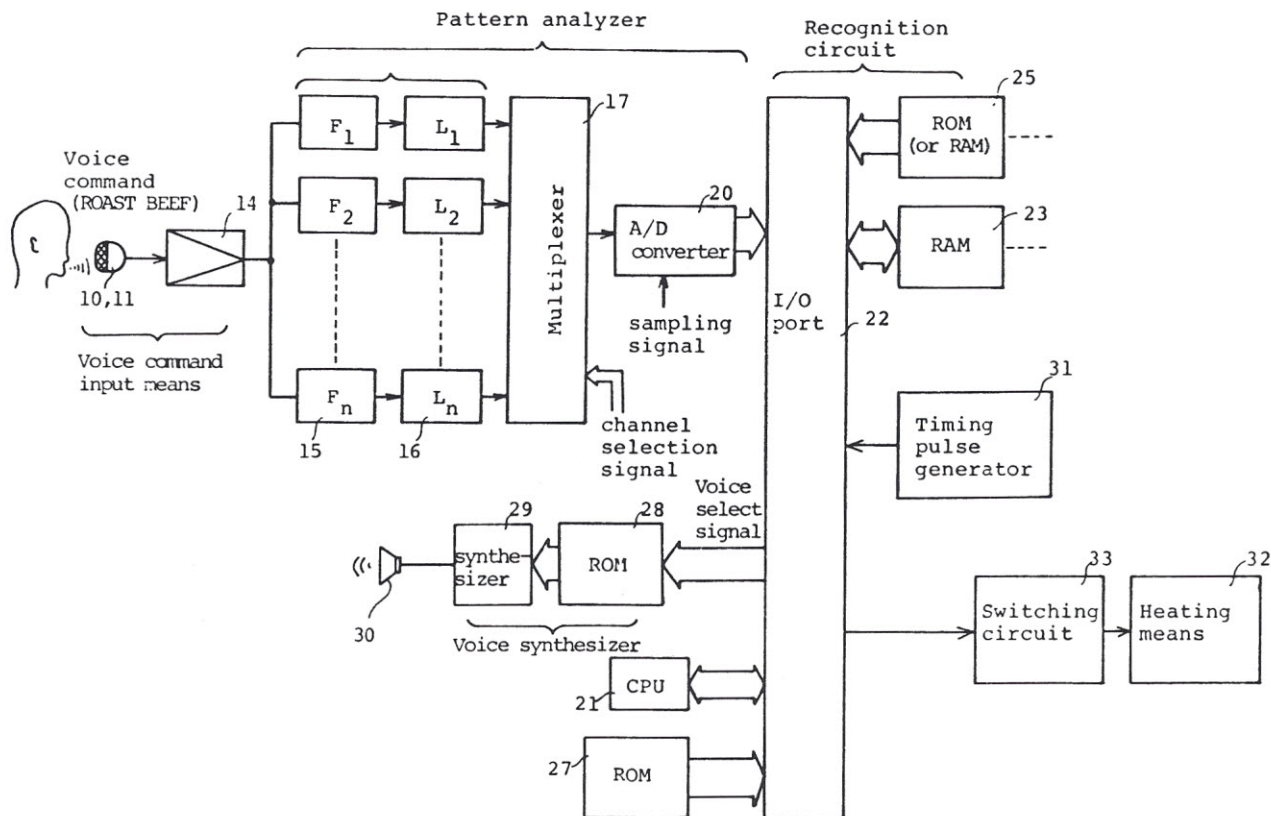


Figure 6. A block diagram showing the major components of the intelligent oven control system.

Continued from page 26

the operator does not understand the synthesized voice and replies "pardon?" this second-level response causes the oven to repeat the synthesized message.

If the operator gives a second-level response which is not among the expected list, the apparatus erases the first-level command it has recognized and restores the apparatus to its first recognition mode. In addition, if a second-level response is not received within a given period of time, the previous command is assumed to have been given erroneously and is erased. If the oven does not recognize the voice command given by the operator as being among the prestored set of commands, the synthesizer generates the message "pardon?" to indicate to the operator that it did not understand the command.

Hardware. The voice recognition and processing circuit is controlled by an eight-bit microprocessor such as the Intel 8080 (see figure 6). The spoken command signal is received by a microphone, and the output is

amplified and fed through a filter bank comprising an array of 10 bandpass filters and 10 lowpass filters. The outputs of the filter bank are connected to an analog multiplexer formed by, for example, three CMOS MC14016B quad analog switches.

Channel switching is controlled by a channel selection signal sent from the microprocessor. The four-bit channel selection signal is decoded by a BCD-to-decimal decoder such as the MC14028B. The multiplexed output is sent to an A/D converter which changes the analog signal to an eight-bit digital signal. The A/D converter may be a monolithic type, such as the MM 5357.

The voice data signal is sampled and written into the input pattern memory. By detecting the end of the voice input signal, the microprocessor counts the time length of the voice pattern and normalizes the time length using the dynamic programming technique described in the *IEEE Transactions on Acoustics, Speech and Signal Processing*, volume ASSP-26, number 1, February 1978, pages 43-49 and ASSP-27, number 6, December 1980,

pages 588-595. The dynamic programming technique compares the reference patterns stored in memory with partially expanded or contracted images of the voice input pattern until it determines the best match.

The following three patents are similar to that of Ueda and Takano and are equally interesting.

- 4,340,797 "Voice Actuated Heating Apparatus"
- 4,340,798 "Voice-Controlled Safety Arrangement Heating Apparatus"
- 4,340,799 "Heating Apparatus With Voice Actuated Door Opening Mechanism"

Each of these describes other modifications and improvements to the intelligent oven.

Copies of all four patents are available from the U.S. Patent and Trademark Office for \$1.00 each. Send orders with payment to: Commissioner of Patents and Trademarks, Washington, DC 20231. □

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Continued from page 37

These four phases are cycled through, one after
another, to simulate a pogo stick hopping. Experimen-
tal control algorithms may be used to control the torque,
 τ , during both the In the air (phase 1) and On the ground
(phase 3) phases of the hopping cycle. For example, to
control θ_1 , leg angle with respect to the vertical at time
of landing, a simple servo controller which monitors θ
can be used to command an appropriate torque at each
time step in the iterative simulation of the In the air phase
of hopping.

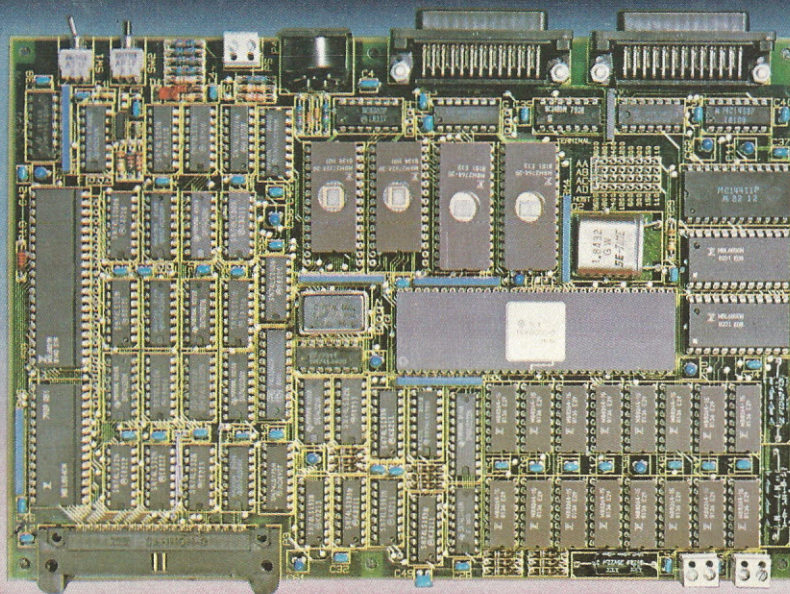
*Acknowledgements: Many thanks are due Dr. Marc Raibert for
introducing me to the dynamic balance problem, and to the
Robotics & Teleoperator Group of the Jet Propulsion Laboratory
for computer facilities.*

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Part I: "Defining Notation," *BYTE*, June 1979, pages 10-34
Part II: "A Neurological Model," *BYTE*, July 1979, pages
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Part III: "A Comparison of the Brain and our Model," *BYTE*,
August 1979, pages 66-80

M.H. Raibert, "A Model for Sensory Motor Control and Learn-
ing," *Biological Cybernetics*. 1978 Vol. 29, pages 29-36

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